2 p.
m.1X

E7.3 10511
CR-131621

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

ERTS-1 Project No. MMC-298

ARCTIC AND SUBARCTIC ENVIRONMENTAL ANALYSES UTILIZING ERTS-1 IMAGERY

(E73-10511) ARCTIC AND SUBARCTIC ENVIRONMENTAL ANALYSES UTILIZING ERTS-1 IMAGERY Bimonthly Progress Report (Army Cold Regions Research and Engineering Lab.) 51 p HC $4.75 CSCL 08L G3/13 N73-22286 Unclas 00511

Fourth Bimonthly Progress Report

23 February 1973 - 23 April 1973

Prepared by

Principal Investigator

Dr. Duwayne M. Anderson - DE 329

Co-Investigators:

Dr. H.L. McKim
Mr. R. K. Haugen
Mr. L.W. Gatto
Dr. C.W. Slaughter
Mr. T. Marlar

Objectives: (Reference NASA Contract S-70253-AG dated 14 June 1972):

* Analyze and map the sediment deposition in harbors, inlets, and docking facilities in the Cook Inlet.

* Map the permafrost areas of Alaska as inferred by vegetative patterns. Compare major tonal and textural permafrost patterns with Mariner imagery.

* Correlate the snowpack cover of Caribou-Poker Creek with stream runoff.

* Map and inventory the icing on the Chena River.

* Items 2 and 4 above are to be correlated with the University of Alaska studies in the same area.

Accomplishments:

Three aspects of the program were emphasized this reporting period: 1. The comparison between major tonal and textural permafrost patterns discernible on ERTS-1 imagery and terrain features visible on Mariner imagery; 2. the correlation between the snowpack cover and stream runoff in the Caribou-Poker Creek watershed; and, 3. the inventory of icings on the Chena River.

Two ERTS-1 scenes of Alaska show permafrost terrain features which are large enough to be seen on Mariner imagery. MSS image 1058-21421 of the south coast of Norton Sound shows patterned ground in the swampy, lowland of the Yukon River delta. The distinct polygonal patterns are approximately 300-500 m across, and occur in a region generally underlain by moderately thick to thin permafrost. The unusually large size of these polygons is remarkable. Comparisons can be made to the polygonal patterns on Mars shown in Mariner 71 image number PLYBK P177, picture 35B. U. S. G. S. aerial imagery of this area shows that these patterns result from the alignment of old beach ridges and the orientation of thaw lakes.

MSS image 1081-20272 shows numerous pingos in the Yukon-Tanana Uplands of interior Alaska. The pingos are conical, elliptical, oval or irregular mounds and are found singly or in clusters. They vary in elevation from 10 to 100 feet and from 25 to 1200 feet in diameter*. Although not presently identified, Martian pingos should be discernible on Mariner 9 imagery. Their presence would indicate the occurrence of ice-rich permafrost on Mars.

Tonal and textural variations of the snow cover apparent on the ERTS imagery is being correlated to snow accumulation, depth and ablation in the Caribou-Poker Creeks watershed. These snow conditions are being monitored and related to potential runoff. This approach can be utilized in high flood risk areas for making regional surveys of flood potential and the data would be useful in reservoir management and

*Holmes, G. W. and H. L. Foster, 1963, Distribution and age of pingos of interior Alaska: Permafrost International Conference, Lafayette, Indiana, p. 88-93.

and flood control. Measurements of the depth and distribution of the snowpack in the entire watershed were made prior to runoff by extensive snow surveys. The distribution of snow in early November is apparent on MSS frames 1103-20402, 1103-20504, 1104-20560, and 1104-20563. All other images for this region have more than 20% cloud cover and are not usable for this investigation.

Several activities have been performed for the inventory of Chena River icings. Preliminary mapping of the Chena watershed was accomplished on MSS scene 1103-20502. Corroborative underflight imagery taken on Mission 209 in July 1972 of the Chena River channel has been reviewed. Ground and aerial surveys of the main channel of the Chena River were made in March, 1973. Color photographs were taken to document the size and location of icings. Numerous small icings were located in the upper Chena and its tributaries. It is believed several of these icings will persist long enough to be observable in April and/or May ERTS imagery. The techniques being developed to monitor icings on ERTS imagery can be used to recommend and perform the appropriate corrective action to reduce or eliminate the adverse effects of icings.

Work to be accomplished next reporting period:

The imagery received since the satellite began to acquire data in February (sun elevation increased to approximately 10°) will be analyzed and the Type III Final Report will be prepared.

Published articles, papers, preprints, abstracts:

Report published in Army Research and Development News Magazine, Vol. 13, No. 8, December 1972 (copy enclosed) "ERTS-1 Imagery .... Arctic and Subarctic Environmental Analysis"

Presentation given at the Dartmouth College Department of Earth Sciences meeting, 28 February 1973.
"Arctic and Subarctic Environmental Analysis Utilizing ERTS-1 Imagery"

Report presented at the ERTS-1 Symposium sponsored by GSFC 5-9 March 1973. (copy enclosed)
"Sediment Distribution and Coastal Processes in Cook Inlet, Alaska"

Report presented at the Second Annual Remote Sensing of Earth Resources Conference, sponsored by the University of Tennessee Space Institute, 26-28 March 1973 (copy enclosed)
"The Use of ERTS-1 Imagery in the Regional Interpretation of Geology, Vegetation, Permafrost Distribution and Estuarine Processes in Alaska"

Presentation given at the New England Junior Science and Humanities Symposium sponsored by the University of Massachusetts Department of Engineering, 5 April 1973.
"The Use of ERTS-1 Imagery in the Analysis of Cold Regions Environments"

Problems:

None

Recommendations:

None

Changes in Standing Order Forms:

None submitted

ERTS Image Descriptor Forms:

None submitted

Data Request Forms submitted:

None submitted

Data Query Forms submitted:

4 December 1972 - print out received
10 January 1973 - print out received
20 February 1973 - print out received
20 April 1973 - pending

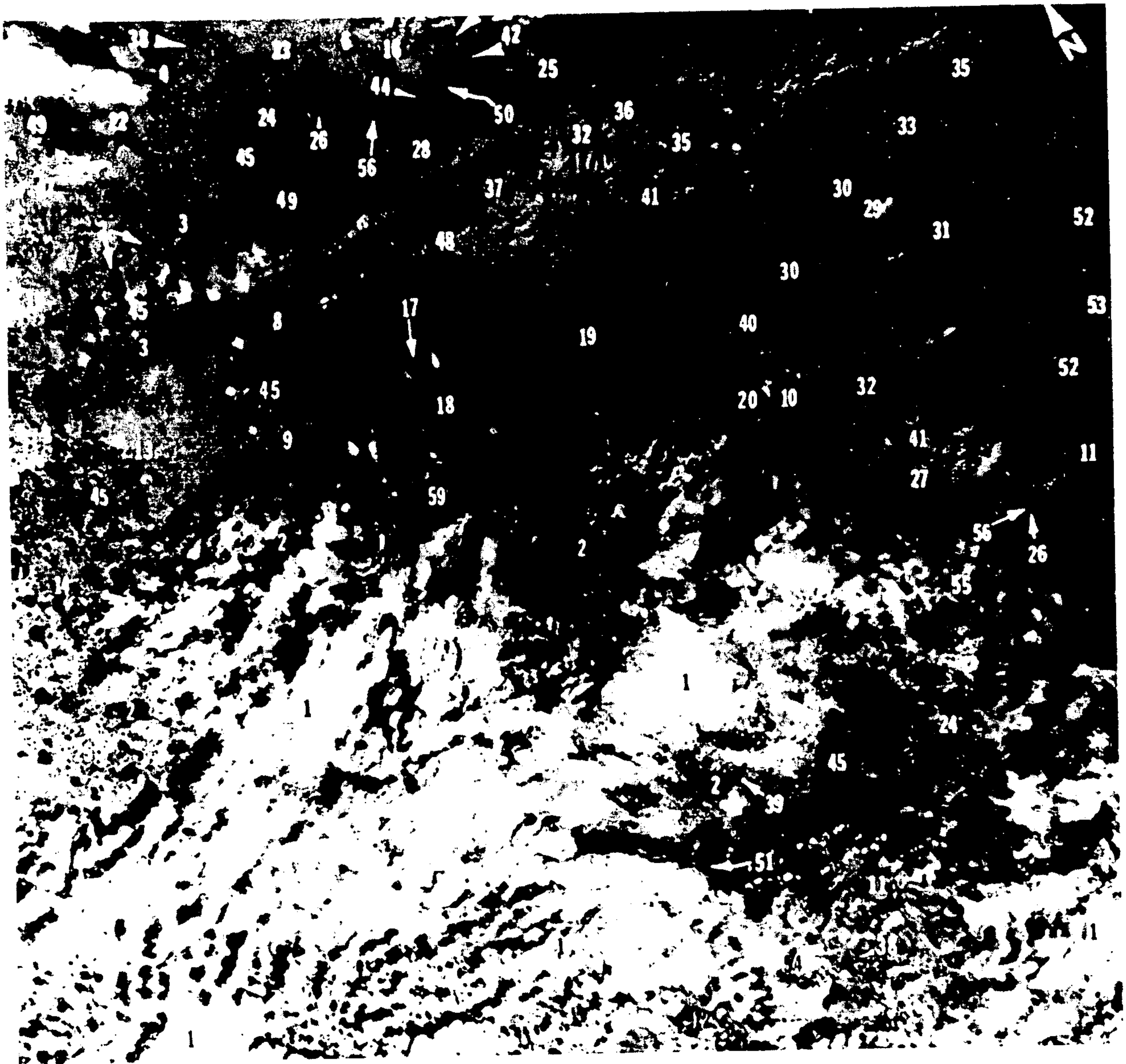
Reprint From
Army Research and Development News Magazine
Vol. 13, No. 8 December 1972

ERTS-1 IMAGERY
Arctic and Subarctic Environmental Analysis

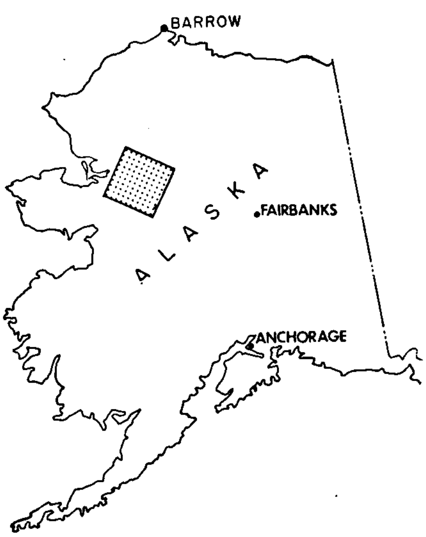
Dr. Duwayne Anderson, Richard Haugen,
Lawrence W. Gatto, Dr. C.W. Slaughter,
Dr. Harlan McKim and Thomas L. Marlar

6

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE



ERTS-1 imagery of 115-mile-square area 250 miles N.W. of Fairbanks, Alaska.



1. Clouds
2. Cloud shadows
3. Kugarak River
4. Kobuk River
5. Ambler River
6. Shungnak River
7. Selby River
8. Rabbitt River
9. Selawik River
10. Dakli River
11. Koyukuk River
12. Kateel River
13. Kawichiark River
14. Tagagawik River
15. Kuchuk Creek
16. Cosmos Creek
17. Kiliovilik Creek
18. Shinilikrok Creek
19. Shiniliaok Creek
20. Wheeler Creek
21. East side of Great Kobuk Sand Dunes
22. Little Kobuk Sand Dunes
23. Pitkik Lake (Oxbow Lake)
24. Meander scars
25. Lakes and ponds
26. Sand bars
27. Solsmunket Lake
28. Tekeaksakrak Lake
29. Forest fire smoke
30. Smoke shadows
31. Recently burnt areas
32. Drainage patterns (stream erosion valleys)
33. Pah River Flats
34. Norutak Hills
35. Lockwood Hills
36. Mountain slope vegetation
37. Pick River
38. Cleared areas (cabins with clearings)
39. Birch Lakes
40. Zane Hills
41. Bedrock outcrops or valley shadows
42. Kobuk village
43. Dahl Creek Airstrip
44. Shungnak Village
45. Swampy, flatland
46. Jade Mountains
47. Waring Mountains
48. Shekluksuk Range
49. Old burned area
50. Shungnak Airstrip
51. Nogahabara Sand Dunes
52. Hogatza River
53. Babantaltlin Hills
54. Three-Day Slough
55. Cutoff Slough
56. Mid-Channel Islands
57. Mauneluk River
58. Kogoluktuk River
59. Purcell Mountain

7

FIRST NUMBERED PAGE OF THIS PART OF DOC.

ERTS-1 IMAGERY . . .

Arctic and Subarctic Environmental Analysis

By Dr. Duwayne Anderson, Richard Haugen, Lawrence W. Gatto, Dr. C. W. Slaughter, Dr. Harlan McKim and Thomas Marlar

Wise utilization of the earth's resources is now acknowledged to be a primary concern of our society. Problems of resource utilization have been dramatized in Alaska, where a severe lack of basic environmental data and understanding has collided with rapidly mounting pressures for extensive development of industries, transportation systems and population centers.

Existing information on Alaska's water cover and distribution, properties, and behavior of permafrost terrain is insufficient for an understanding of its various environments and their interrelationships.

The history of construction and technological development in Alaska dramatically illustrates the difficulties caused by environmental extremes; it also shows the possibility of serious unforeseen consequences of disturbing established environmental balances.

Scientists at the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, N.H., are studying the arctic and subarctic environments of Alaska, using the information from the NASA Earth Resources Technology Satellite, ERTS-1, launched July 23, 1972.

(For a detailed explanation of the over-all scope of ERTS-1, see lead feature article beginning on page 38 of the August 1972 edition of the *Army R&D Newsmagazine.*)

Since its inception in 1961, CRREL has continued an active role in basic and applied research and engineering in cold regions. A major objective of the ERTS study is the development of practical knowledge that permits man to live in greater harmony with the cold regions environment, and to identify and utilize its existing resources in the most favorable manner.

In the ERTS-1 program, the CRREL will study a number of aspects of the Alaskan environment. The relationship of snow pack and river icing hydrology is one of the more important areas of investigation. A comparison of the major tonal and textural permafrost geomorphic patterns on ERTS imagery will be made with that of Mariners 6, 7, and 9 to present a plausible interpretation of the various terrain patterns of Mars.

ERTS-1 imagery will be used in another major effort to study surface circulation and coastal sedimentation processes in Cook Inlet, Alaska, which leads to Anchorage harbor. The information derived will be applied to the maintenance and improvement of navigable waters, harbor construction and siltation problems.

ERTS imagery will be used in a third area of primary concern to evaluate permafrost-vegetative relationships, permafrost distribution, its seasonal thaw regime and environmental relationships in interior Alaska. Permafrost is a major environmental and engineering factor in Alaska and other high-latitude regions.

This perennially frozen ground is a result of complex interaction among such environmental factors as local microclimate, the insulating qualities of organic and vegetative cover, and the texture and moisture content of soils. In central Alaska, the distribution of permafrost is discontinuous because the present climate in this area is near the threshold values for the continued existence of permafrost.

Only in well-protected locations, such as north-facing slopes, shaded valley bottoms and high elevations within the region does permafrost exist. Minor changes in thermal regime, whether natural or man-induced, can produce major alterations in permafrost landscapes.

In all of these studies, interpretation of the ERTS imagery will be accomplished through comparison with photographs of selected areas taken by low-flying aircraft and by actual ground-level observations.

ERTS-1 utilizes multispectral scanner and return vidicon cameras that record information in seven spectral bands. The data is returned to the three main ERTS tracking stations: Fairbanks, Goldstone and Goddard.

One of the initial scenes of Alaska, acquired during orbit 44 on July 26, is shown in Figure 1. The image is a composite made from data acquired in the green, red and an infrared band of the multispectral scanner.

Shown is a 115-mile square located 240 miles northwest of Fairbanks that includes Kobuk and Shungnak villages. The resolution varies with the gross shape and tone contrast of a feature. Rounded features (i.e. streams) to 150 feet wide are visible. The resolution of this composite and the individual bands is considerably better than anticipated prior to launch.

Registration accuracy of the color printing process causes features that are distinct on single-band photos to become somewhat blurred on composites, but the resolution is still remarkably good and a thorough interpretation of the regional features can be made. Clouds (1) cover a large portion of the lower half of the photograph. Cumulus clouds at approximately 8,500 feet altitude cap the higher peaks of this area while cirrus clouds occur at a higher level. Cloud shadows (2), reflecting the cloud shapes rather well, may be confused with the ponds and lakes (25) of this area.

The areas burned by forest fires are very prominent features. At the time this photograph was taken a forest fire was burning in the Pah River flats (33) area. By July 26, 1972, this fire had burned 81,000 acres. The smoke (29) and smoke shadows (30) are readily apparent. The recently burned areas (31) appear black while old burned areas (49) show some evidence of revegetation.

Evidence of a variety of human activity in this area is visible. Two bush airstrips can be seen, the Shungnak airstrip (50), and the Dahl Creek airstrip (43). Both are located near small villages along the Kobuk River, Shungnak village (44) and Kobuk village (42), respectively. A number of cleared areas (38) were located. These may be homestead sites and the presence of cabins was verified with underflight photography.

Kugarak River (3) and its tributaries, Kawichiark River (13), Kuchuk Creek (15), and Rabbitt River (8) are well-defined by the contrast between the vegetation bordering the streams and the surrounding vegetation. They drain a significant portion of the photographed area, including the Waring Mountains (47), the Sheklukshuk Range (48), and the swampy flatlands bordering the Waring Mountains on the south and east and the Sheklukshuk Range on the north, west and southwest.

The Kobuk River (4), one of the major rivers shown, flows westerly into the Hotham Inlet of Kotzebue Sound, about 80 miles west of the photo area. Along the stream course, meanders are abundant and meander scars (24) and oxbow lakes, such as Pitkik Lake (23), mark channel positions of a former time.

Erosion along the river is evidenced by the deposition of sands and gravel on the inside of meanders. These deposits in some places occur as sand bars (26), point bar deposits, which appear as lighter areas along the stream course, and as mid-channel islands (56) in braided streams.

Some of the more obvious rivers and streams tributary to the Kobuk River are: Ambler River (5), Shungnak River

(Continued on page 30)

Arctic and Subarctic Environmental Analysis

(Continued from page 29)
(6), Cosmos Creek (16), Koguluktuk River (58), Mauneluk River (57), Pick River (37) and the Selby River (7). The banks of these are outlined by distinct vegetation patterns along the stream course. Trees are more abundant and dense along the streams' banks but scattered in the bordering lowland areas.

Dendritic drainage patterns are obvious throughout the photo, but the best example is present on the south and east slopes of the Waring Mountains (47). Here the alternating dark and light vegetation patterns respectively reflect the stream and inter-stream areas.

Another major river, the Selawik (9), flows in a westerly direction to Selawik Lake, an embayment of Kotzebue Sound, not shown on the photo. This river has numerous meanders and drains the western portion of the Zane Hills (40), the mountainous region around Purcell Mountain (59), and the swampy flatland are (45) in the photo.

Some of the tributaries of the Selawik are defined by the dark vegetative patterns along the stream courses: Tagagawik River (14), Kiliovilik Creek (17), Shinilikrok (18), and Shiniliaok Creek (19). The area around the Kugarak-Selawik River junction is swampy flatland with numerous lakes and ponds.

Dakli River (10) and its tributary Wheeler Creek (20), which are defined by the distinct vegetative patterns along these streams, are 4th- and 3rd-order streams, respectively, according to the Strahler-modified Horton classification. These streams drain the southwestern portion of the Zane Hills (40), and the northeast portion of the mountainous area around Purcell Mountain. At the southern portion of the Dakli River, near its junction with the Koyukuk River (11), the surrounding area is swampy, with many ponds and lakes.

The Koyukuk River (11) shows extensive meandering and has numerous meander scars and sloughs along its course. Three-Day Slough (54) and Cutoff Slough (55) are two examples. The Koyukuk and its tributaries (e.g. Kateel River) (12) drain most of the area in the lower right quarter of the photo. It flows over very flat, swampy land characteristic of a geomorphically old-age area.

The Babantaltlin Hills (53) and the meandering Hogatza River (52) are located Southeast of the Pah River flats fire. The area is extensively forested, with many lakes. Along the Hogatza River are numerous point bar deposits.

The Lockwood Hills (35), Zane Hills (40), Jade Mountains (46), and the Norutak Hills (34) show extensive bedrock exposures (41) on the peaks and crest lines. These appear as dark areas outlined by lighter vegetation. Extensive stream erosion valleys (32) with dendritic drainage patterns are visible on the mountains.

Vegetation tones in the photo are attributable to the type of surface material, climatic parameters and slope. Mountain slope forests (36) are visible in the hilly areas, while the bog vegetation in the swampy areas is a lighter shade and also quite distinctive. The dark vegetation tones following stream valleys are very useful in tracing the river courses on the photo.

The numerous lakes and ponds on the photo are varied in size and shape. Tekeaksakrak Lake (28), nearly two miles long, and Solsmunket Lake (27), slightly larger than two miles, are two of the larger lakes on the photo. They are similar in shape with an elongate N-S axis. Birch Lakes (39) is one mile across with a circular shape. The multitude of lakes and ponds indicates poor drainage in the lowlands and a proximity to base level.

Wind deposition was active during the Pleistocene in the photo area. Sites of sand deposition are apparent as irregular-shaped, light-colored areas; the Little Kobuk Sand Dunes (22), the east side of the Great Kobuk Sand Dunes (21), and (somewhat hidden by clouds) the Nogahabara Sand Dunes (51) southwest of Birch Lakes. These deposits result from wind erosion across extensive periglacial outwash plains, with subsequent deposition in areas where the wind-borne materials are retained.

In view of the lack of environmental information in arctic and subarctic areas, the advantages of surveys by polar-orbiting satellites are obvious. Until now, obtaining environmental data in polar regions has been very difficult and the launching of the ERTS satellite comes at a most opportune time.

Scientists at CRREL look forward to an immediate yield of information vital to a more rational, safe and productive program of development of arctic and subarctic areas, by methods that will have a minimal impact on the environments found in Alaska.

PREPRINT

THE USE OF ERTS-1 IMAGERY IN THE REGIONAL INTERPRETATION OF GEOLOGY, VEGETATION, PERMAFROST DISTRIBUTION AND ESTUARINE PROCESSES IN ALASKA

D.M. Anderson, H.L. McKim, L.W. Gatto,
R.K. Haugen and W.K. Crowder

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, N.H.

Abstract

A preliminary study has been made of the value of satellite imagery in synoptic surveys of coastal sedimentation and related processes in Cook Inlet, Alaska, and of the distribution and environmental interrelationships of permafrost terrain. ERTS multispectral scanner (MSS) imagery was the primary data source for this investigation. Aerial underflight imagery and ground observations of selected sites were secondary data sources. Emphasis has been placed on evaluating the feasibility of mapping permafrost terrain from textural and tonal patterns related to surficial geology and vegetation. A mosaic of a 153,400-km^2 area in north central Alaska has been prepared at a scale of 1:1,000,000. Seven surficial geology, eight vegetative cover and four permafrost terrain units were defined and delineated. Many geomorphic features were also recognized: thaw lakes, stream drainage patterns, glacial moraines, cirques, abandoned glacial valleys and volcanic cones. Preliminary analysis of the regional hydrologic and oceanographic processes in Cook Inlet has been accomplished. It is evident that the distribution of sediments and regional circulation patterns can be monitored using satellite imagery.

Acknowledgments: The assistance of A. Petrone, C.W. Slaughter and T.L. Marlar in the preparation of this paper is appreciated.

Introduction

Problems of resource utilization have been particularly dramatized in Alaska. A severe lack of basic environmental data and understanding has collided with rapidly mounting pressures for extensive development of extractive industries, transportation systems and population centers. The existing information on hydrology, in the broadest sense, and on the distribution, properties and behavior of permafrost terrain is insufficient for an understanding of the various environments and their interrelationships. The history of construction and technological development in these areas not only dramatically illustrates the difficulties caused by environmental extremes but also the possibility of serious unforeseen consequences of disturbing established environmental equilibria.

Gemini and Apollo photography clearly illustrated the importance of satellite data in the study of oceanography, geology and forestry.[1] Prior to launch, it seemed likely that the analysis of ERTS imagery would greatly increase our understanding of these disciplines and their interplay throughout Alaska and other cold regions. This expectation already has been realized to a large degree.

The occurrence and properties of permafrost are major environmental factors throughout Alaska and other high latitude regions. Its existence and distribution are the result of complex interactions among environmental factors, e.g. local microclimate, plant cover, the insulating qualities of the organic and vegetative layers, texture and moisture content of the soil, and topographic position. In interior Alaska, the distribution of permafrost is discontinuous because the present climate in this area is near the threshold values for the continued existence of permafrost. Only in well protected locations such as north-facing slopes, shaded valley bottoms or high elevations does permafrost exist. Minor changes in the thermal regime, whether natural or man-induced, can produce major alterations in the permafrost. ERTS-1 imagery has proven invaluable in investigating the relationships between vegetation, hydrology, surficial geology, and other environmental factors affecting the distribution and conditions of permafrost terrain.

The area selected for the study of coastal processes is the Cook Inlet region in south central Alaska. Wave action is limited in the inlet because of limited fetch and variable wind direction and velocity. Therefore, sedimentation and circulation are predominantly controlled by tidal currents. These

Table 1 Marine phenomena observed

Group I. Easily detected
- A. Regional sedimentation phenomena
  - 1. Sediment source area
  - 2. Sediment plumes at river mouths
  - 3. Turbidity patterns and relative sedimentation rates in rivers, estuaries, fiords, embayments, harbors and deep water facilities
- B. Regional surface circulation patterns
- C. Direction, strength and duration of near-shore and long-shore currents as inferred from coastal landforms

Group II. Occasionally detected
- A. Current, wave and tidal processes as indicated by sun glint
- B. Navigational hazards created by changes in the extent and morphology of tidal flats in areas with a large tidal range and extensive tidal flats
- C. Effects of harbor and channel structures on local marine processes
- D. Shelving and bottom morphology

currents are often strong because of the large tidal range. Tide currents of 2-3 knots occur at the mouth of the inlet and their velocity increases toward its head.[2 3] Tidal bores, rips and swirls frequently occur. The high silt content causes these strong currents to be visible on the satellite images; thus Cook Inlet is an ideal region for an oceanographic study.

Listed in Table 1 and discussed further below are some of the coastal marine processes that are being observed, analyzed and monitored. The resolution of the ERTS imagery is approximately 50 m for linear features and 160 m for circular features;[4] thus a number of interesting coastal processes are evident. The large amount of image sidelap on each ERTS-1 scene is of great value for investigations in Alaska. It increases the amount of repetitive coverage on successive daily orbits in high latitudes. This is useful because the frequent cloud cover and low sun angle in winter, characteristic of Alaska, make for observational difficulties. Table 2 lists cloud cover statistics for 20 stations throughout Alaska, averaged for a seven-year period. In general, most locations have an average of 75% cloud cover during the year. Sixty percent of approximately 1200 individual scenes of Alaska received to date are at least 50% obscured by clouds. Since 5 November 1972 when the sun elevation reached a value of less

Table 2 Cloud cover, 20 stations in Alaska, seven-year mean

0 = clear sky, 10 = complete cloud cover

January	6.7	May	7.7	September	8.0
February	7.2	June	8.0	October	7.9
March	7.0	July	8.4	November	7.7
April	7.2	August	8.3	December	7.4

than 9 degrees the MSS system has not acquired imagery of Alaska. Images taken when the sun angle was less than 15 degrees are so dark and have such extensive shadows that special photo processing is required to make them usable. ERTS-1 acquires images of each location in Alaska on three successive days. Since the reported cloud cover is not always opaque to the satellite sensors and the sun angle is low only from November through February, several images will ultimately be obtained of the locations and phenomena of interest before the ERTS-1 mission is concluded.

Preliminary Results

The first usable ERTS-1 images for our investigation were obtained during orbit 30 on 25 July 1972. Since then more than 1200 individual return beam vidicon (RBV) and MSS scenes have been received and reviewed. Those images that are relatively cloud-free and taken when the sun elevation was acceptable have been used for interpretation and to construct a photomosaic of Alaska which is presently 85% complete.

Of the repetitive imagery received to date the major cloud-free portion is of central Alaska. Figure 2 is a photomosaic of part of this area. Early emphasis was placed on evaluating the feasibility of mapping permafrost terrain from textural and tonal patterns related to surficial geology and vegetation. The feasibility of rapidly producing accurate thematic maps directly from ERTS-1 imagery has been demonstrated.[5] A surficial geology map has been prepared at a scale of 1:1,000,000. Seven geologic units were defined and delineated in a 153,400-km^2 area in north central Alaska (Fig. 3). Vegetation and permafrost terrain maps have also been prepared at the same scale. Eight vegetation cover units and four permafrost terrain units were defined and mapped. In addition many geomorphic features unique to this area were recognized. Thaw lakes, glacial moraines, cirques, and abandoned glacial valleys for example are among the easily discernible arctic land forms. Classic stream features such as oxbows, meander

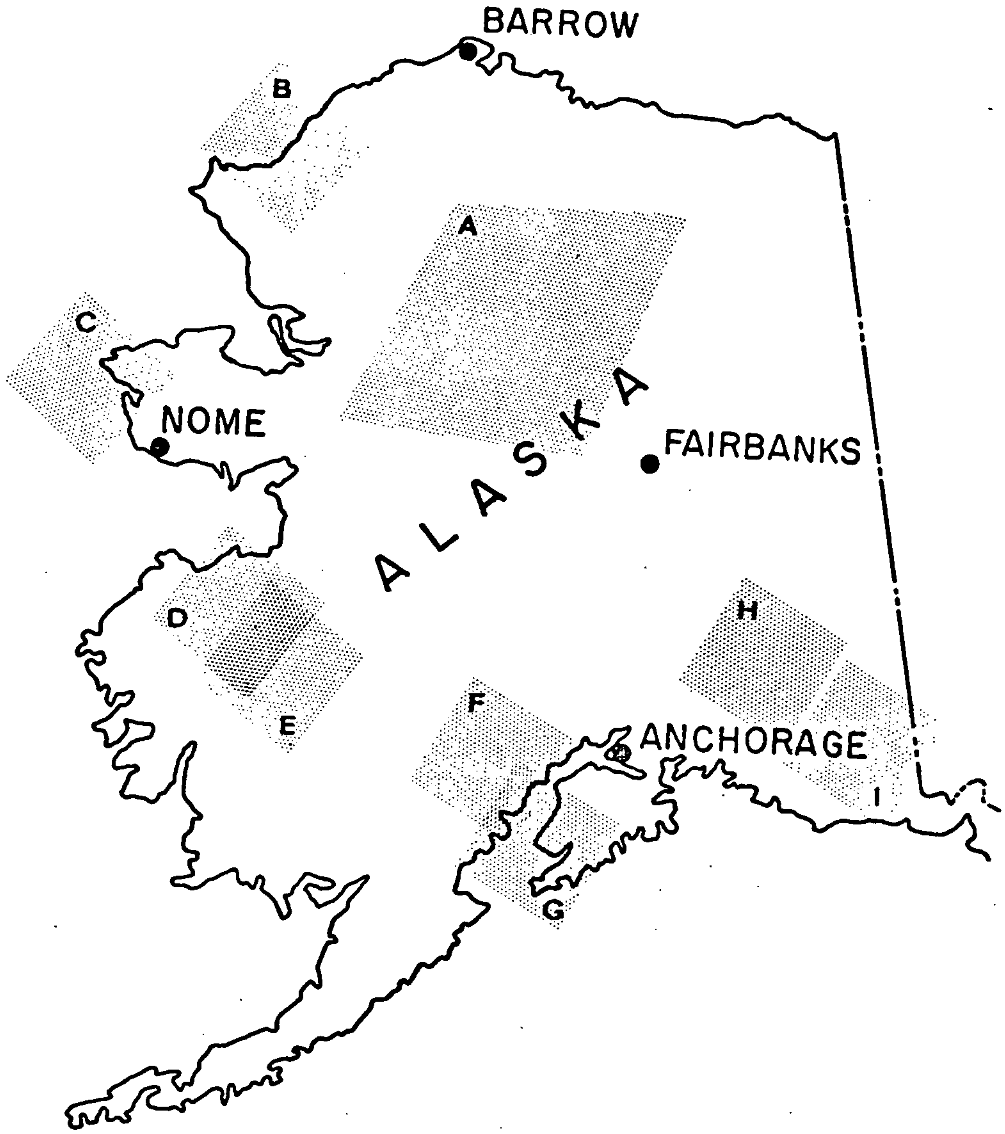


Fig. 1 Site location of satellite images: Fig. 2 (A), Fig. 6 (D), Fig. 7 (C), Fig. 8 (E), Fig. 9 (H), Fig. 10 (B), Fig. 11 (I), Fig. 12 (F), Fig. 13 (G).

scars, point bars, braided channels and chutes are also remarkably well defined.

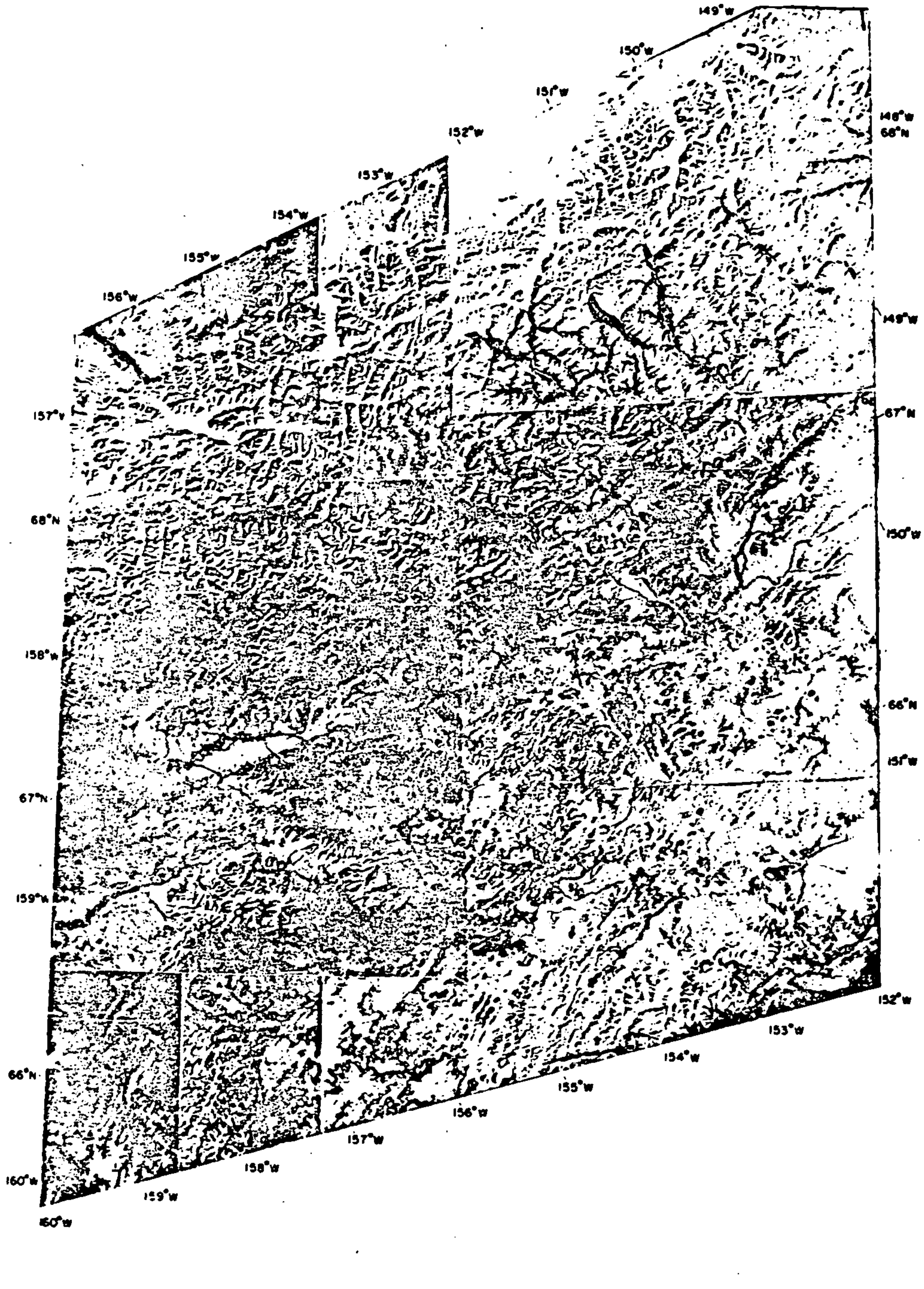


Fig. 2 Uncontrolled photomosaic of a 153,400-km^2 area in north central Alaska (scale 1:3,200,000).

Surficial Geology

The surficial geology was mapped with the aid of stereo pairs and reference to published maps and other available ground truth. Seven recognizable units were defined (Fig. 3). Bedrock (b) consists of in situ bedrock and very coarse rubbly bedrock colluvium primarily confined to steep slopes and mountain crestlines. Bedrock-colluvium (bc) is composed of coarse- to fine-grained deposits occurring on moderate to steep slopes in mountainous terrain and rolling uplands which have minor scattered bedrock exposures restricted to uppermost slopes and crestlines. Alluvial-glaciofluvial deposits (Qag) are fine- to coarse-grained sediments derived from reworked glacial and alluvial deposits, morainal deposits, till, and outwash gravels and sands. These deposits occur in part on modified morainal topography and large alluvial terraces. Fluvial-lacustrine deposits(Qfl) consist of fine-grained sands and silts associated with abandoned floodplains and low-lying terraces. They may include windblown sand and silts. Undifferentiated alluvial deposits (Qal) are fine- and medium-grained alluvial fan, terrace, stream and eolian deposits. Fluvial deposits (Qfp) are fine- and medium-grained silts and sands, generally well rounded, associated with modern floodplains and low-lying terraces. Eolian deposits (Qe) are fine-grained windblown sediments, deposited on gently to moderately sloping hills and low-lying flatlands and include areas of actively drifting dunes.

Vegetation

Vegetation differences are apparent primarily through tonal rather than textural patterns. The tonal differences appear to be related to vegetation density and species composition. Eight density levels have been identified and mapped (Fig. 4):

Fc: Tall to moderately tall, closely spaced spruce-hardwood forest. White and black spruce with paper birch, aspen, and balsam poplar on moderately to well-drained sites such as active floodplains, mountain slopes (especially southern slopes) and highland areas.

Fou: Plant association same as Fc, but cover appears less dense. Ecological setting as Fc, although it extends to somewhat less favorable habitats.

Fo: Open black spruce forest. Stunted, open tree growth includes tamarack, white birch and white spruce in addition to

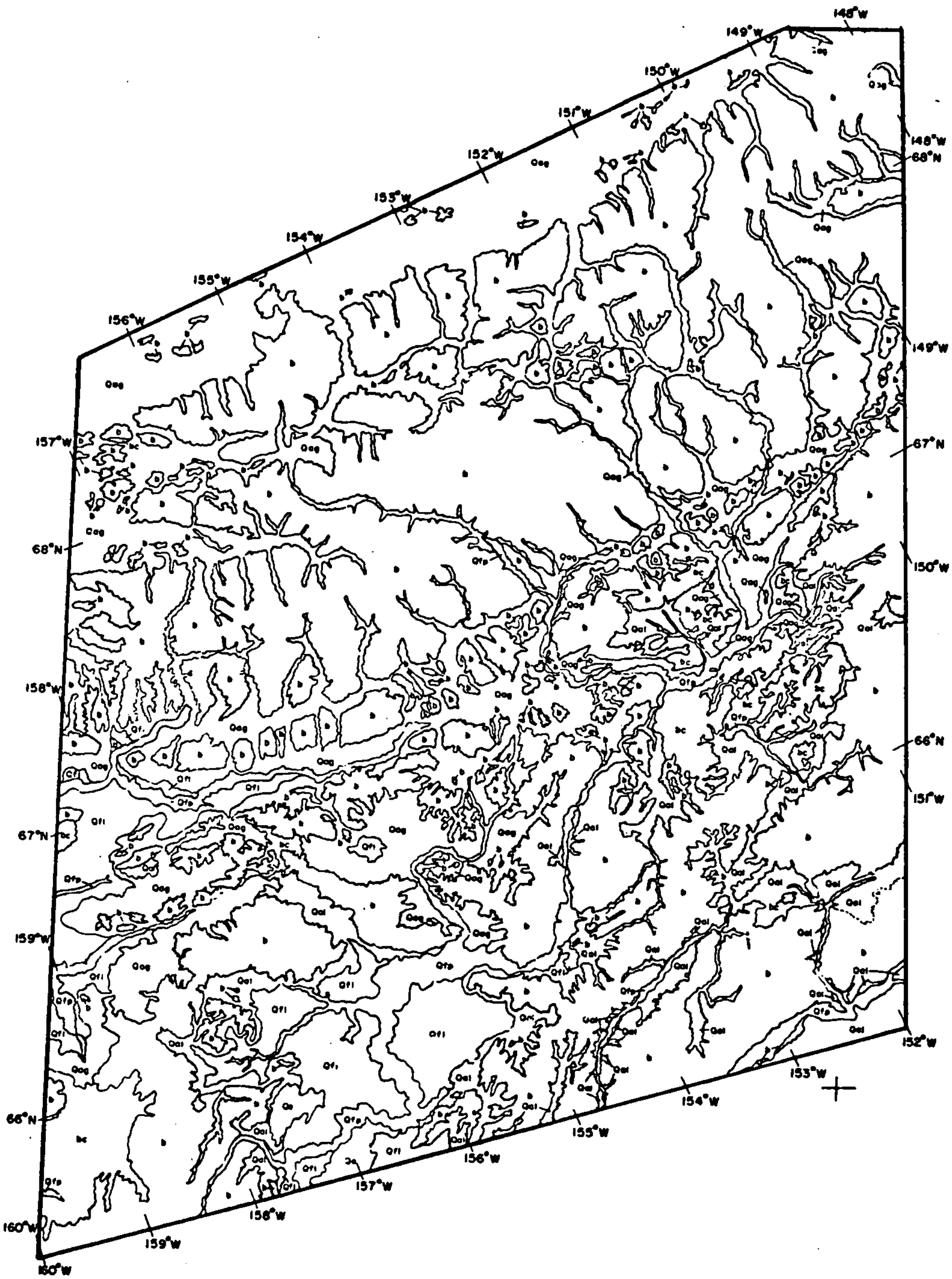


Fig. 3 Surficial geology map.

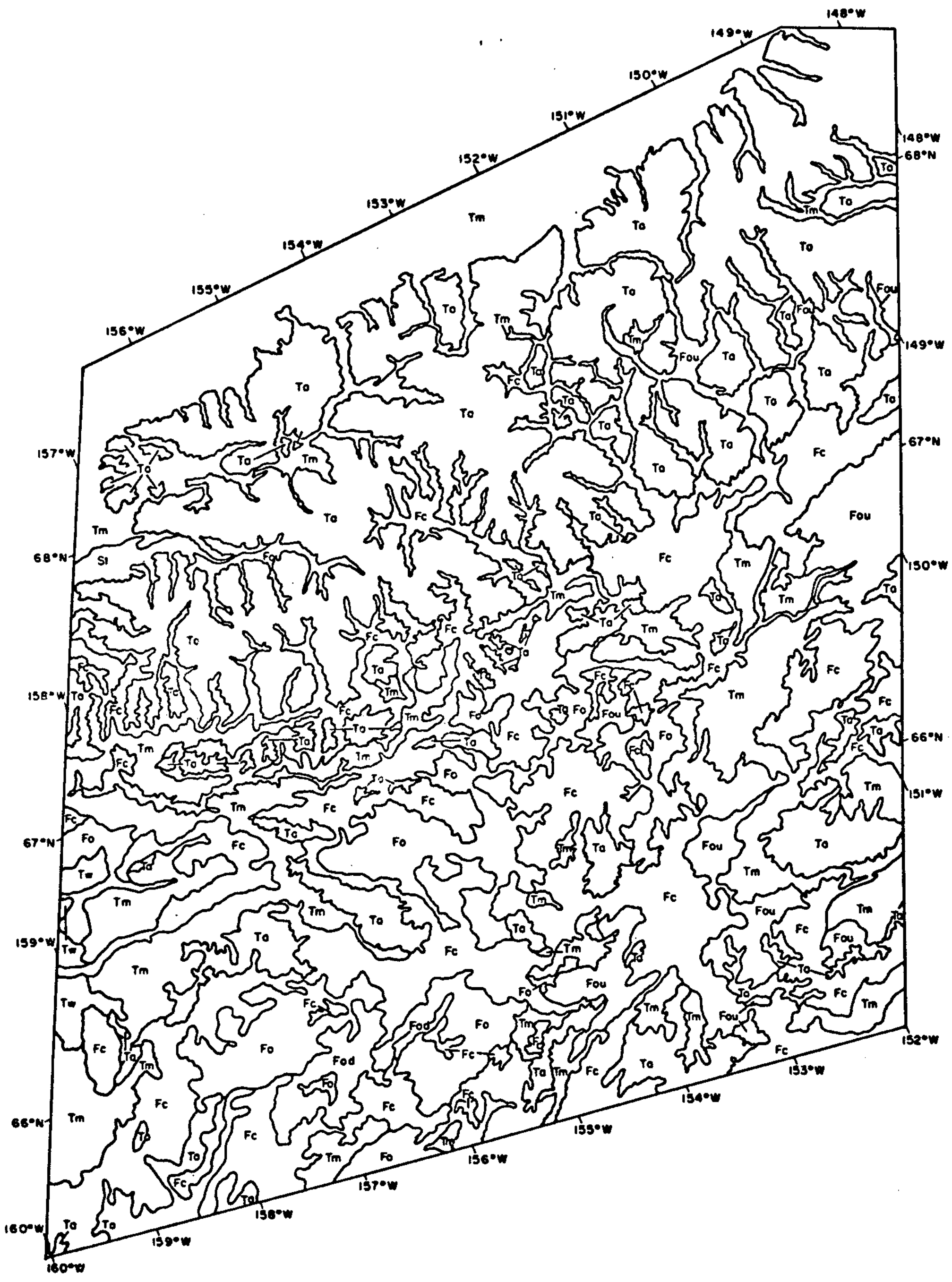


Fig. 4 Vegetation map.

the dominant black spruce. Thick moss, grasses, and heath comprise the ground cover.

Fod: Open black and white spruce forest, confined to several isolated areas where the forest has overgrown and stabilized sand dunes. The forest tends to be open, but better drained and not as stunted as within the Fo class.

Tm: Moist tundra, occupying vast areas of poor to moderately drained topography. Contains some stunted black spruce within the southern two thirds of the study area. Cottongrass tussocks are the dominant vegetation form, with sedges and dwarf shrubs where tussocks are absent.

Tw: Wet tundra. Sedge and cottongrass, with few woody plants. Distinguished from Tm by the presence of many thaw lakes and wet areas.

St: Shrub thickets. Dense thickets of alders, willows, blueberries and other woody berry shrubs are found in coastal areas and floodplains north of the timberline. Extensive areas of this association in the northern foothills and indicated on existing vegetation maps. However a distinctive pattern is not visible in the ERTS mosaic because of an extensive snow cover.

Ta: Alpine tundra. Primarily barren, but locally dominated by low heath shrubs, prostrate willows and dwarf herbs. Generally found at elevations over 2000 feet within the mosaic area.

Vegetation affects the thermal exchange between the atmosphere and the lithosphere, and the moisture regime in frozen soils.[6] It retards soil warming in the summer and cooling in the winter, but the depth of the active layer also depends on other variables, such as the depth of winter snow and drainage conditions during summer. A vegetation association - depth of thaw relationship where permafrost is present in the discontinuous permafrost zone is shown in Table 3.

Permafrost

The geographical distribution of permafrost in a particular area is dependent upon its past and present environmental regimes. The depth of the active layer is dependent on present relationships of soil type, drainage, moisture content, vegetative cover, topographic setting and climatic regimes.[8, 9] Existing maps of permafrost distribution are general, primarily because of lack of more extensive and detailed data.[10] The

Table 3 Relationship between vegetation association and depth of thaw[7]

Vegetation	Depth of thaw (m)
Tall willows on floodplains	2.4
Mixed alder, willow, white birch	1.2
Mixed stands of white spruce and white birch	0.6-0.9
Black spruce in tundra or muskeg	0.3

delineation of permafrost boundaries from conventional aerial photography is difficult and requires ground studies to confirm. Moreover, it does not lend itself conveniently to the mapping of large areas. There is no precedent study on the distribution of permafrost terrain utilizing imagery of the scale and resolution available with ERTS imagery. Consequently, it could not be known in advance the extent to which subtle tonal and textural changes on the MSS images would show large scale patterns not otherwise discernible and useful in differentiating various types of permafrost terrain. Fortunately, the MSS imagery exceeded expectation in this respect.

Four permafrost terrains have been mapped based on the interpretation of surficial geology and the probable depth of thaw inferred from the vegetative cover (Fig. 5). The bedrock (m) terrain is characterized by a few scattered taliks and a thaw depth of 0.3-1.0 m except on south-facing slopes where thaw depths may exceed 2 m. Soils are coarse-textured and shallow. Alpine vegetation occurs on the highest, steepest area with black spruce and paper birch on the north-facing slopes. The principal trees on south-facing slopes are white spruce, paper birch, quaking aspen and alder. The alluvium-colluvium (u) permafrost terrain has numerous taliks and a thaw depth of < 0.5 m in areas of poor drainage and 0.5-2.0 m on moderately to well-drained slopes. Fine-grained, shallow soils occur on steep slopes and medium- to fine-grained, deep soils on gentle slopes. Alpine vegetation occurs on summit positions and black spruce and paper birch on north-facing slopes. White spruce, quaking aspen and alders are found on the south-facing slopes. Moist tundra occurs on poorly drained footslope positions. The active floodplain (l_1) terrain is characterized by numerous taliks, a thaw depth of more than 2.0 m, and fine-grained, deep soils. Balsam poplar, paper birch and white and black spruce dominate. The fourth permafrost terrain unit, abandoned floodplain and terrace (l_2), is characterized by numerous taliks and many small thaw lakes. Soils are fine-grained and shallow with permafrost occurring

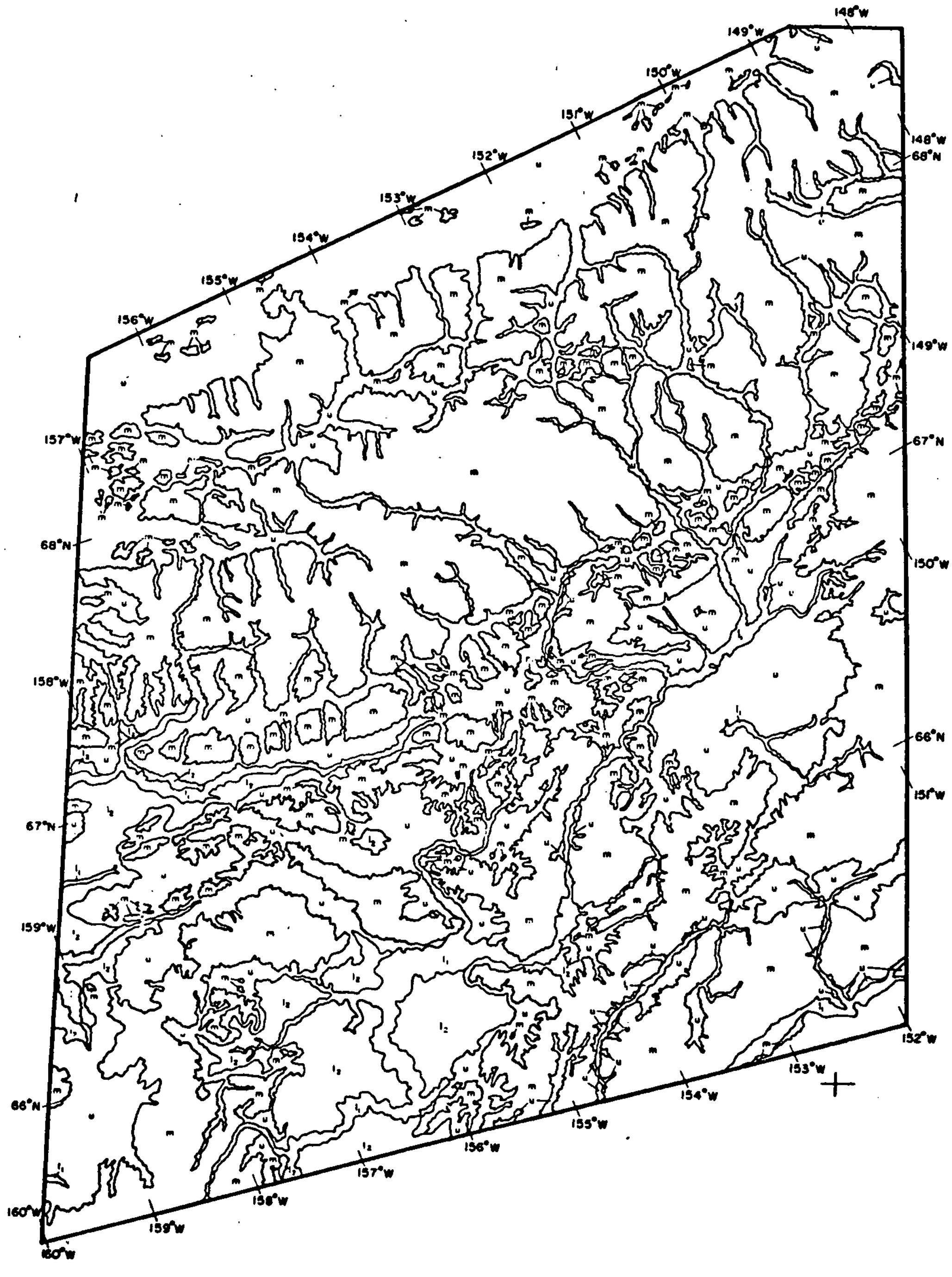


Fig. 5 Permafrost terrain map.

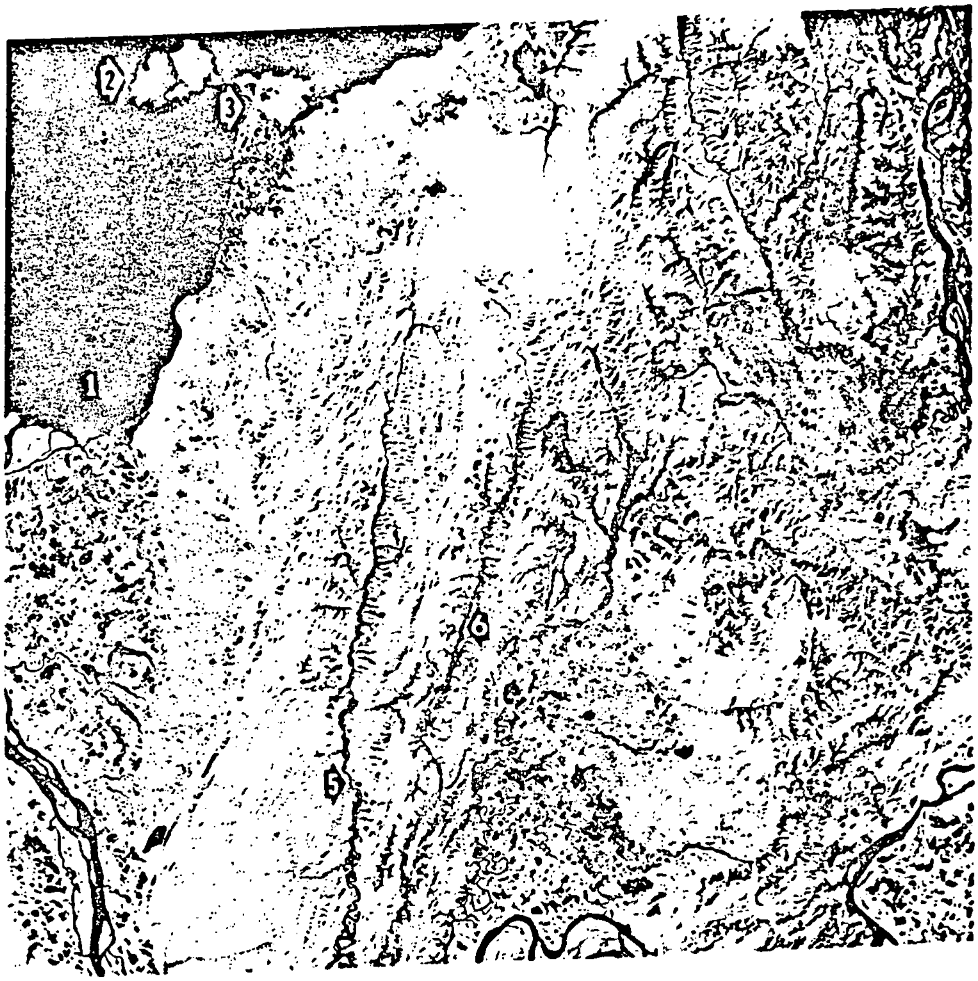


Fig. 6 Southern coast of Norton Sound.

at depths usually < 0.5 m. Vegetation includes moss, lichens, low lying shrubs and black spruce.

Identification and Interpretation of Geomorphic Features

Selected ERTS-1 MSS images have been examined in detail to evaluate the utility of ERTS data in the identification and interpretation of geomorphic features throughout Alaska. The northwest portion of MSS image 1058-21421-7 (Fig. 6) shows Pastol Bay (1), Stuart (2) and St. Michael (3) Islands and the southern coast of Norton Sound. Patterned ground (4) is apparent in the swampy lowland of the Yukon River delta. The distinct polygonal patterns are approximately 300-500 m across, and occur in a region generally underlain by moderately

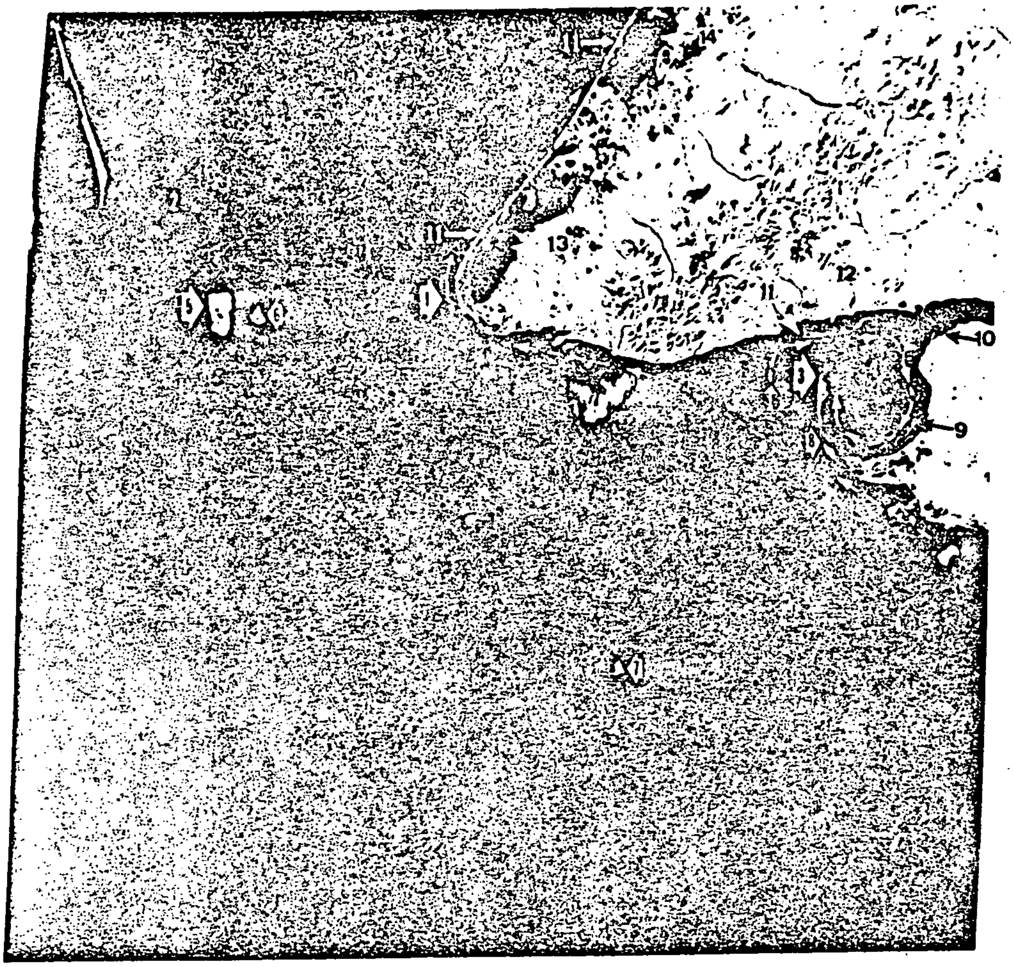


Fig. 7 Coastal features along the west coast of Seward Peninsula.

thick permafrost. The drainage patterns of the Andreafsky (5) and East Fork (6) Rivers, in the hilly areas, are structurally controlled trellis patterns with the primary geologic structure predominantly oriented in a NE-SW direction.

The relationship between coastal morphology and nearshore currents is well illustrated in image 1010-22153-7 (Fig. 7) of the west coast of the Seward Peninsula. Cape Prince of Wales (1) in the Bering Strait (2), Point Spencer (3) in Port Clarence (4), Big Diomede (5), Little Diomede (6), and King (7) Islands are apparent in this image. The predominant direction of flow along this coast is northerly as inferred from the orientation of the Point Spencer Spit (8), baymouth bars (11), and cuspate forelands (10) along the shore. Jones Point Spit (9) indicates a circular flow pattern within Port

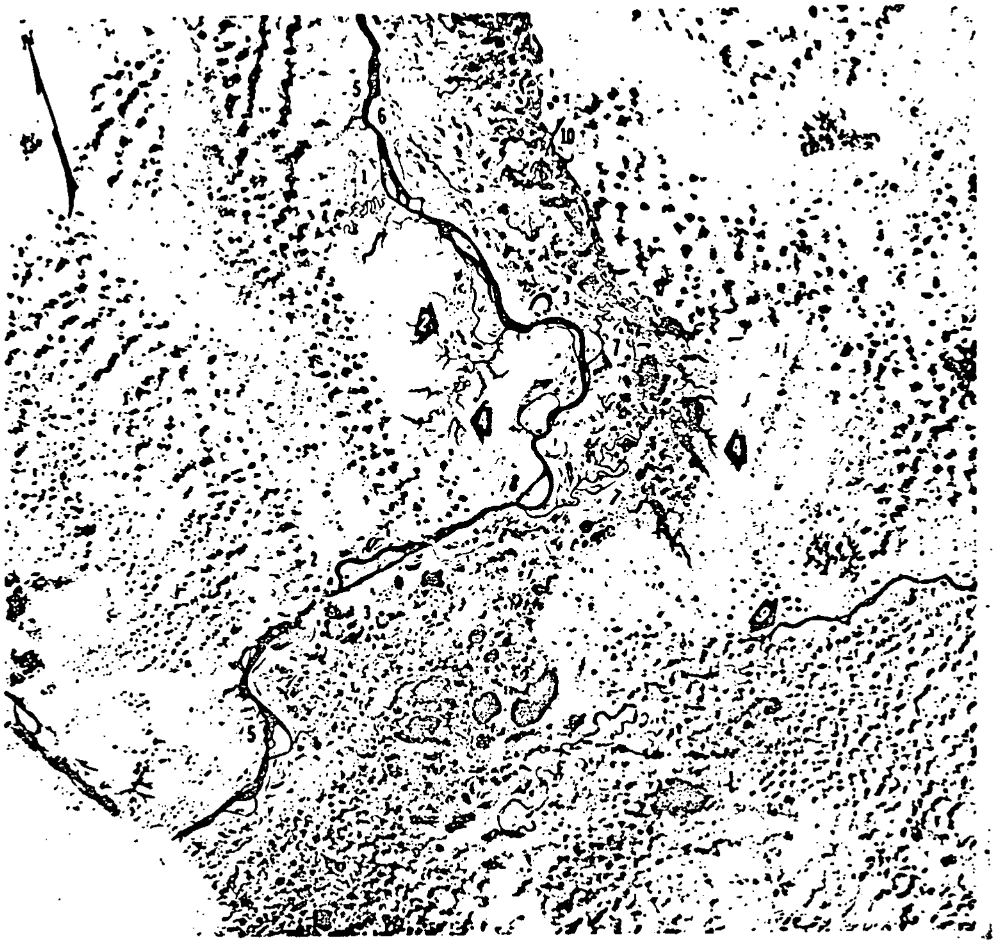


Fig. 8 Yukon River in the Innoko Lowlands of Alaska.

Clarence. Baymouth bars have formed seaward from older coastlines to form Breving (12), Lopp (13), and Arctic (14) lagoons.

MSS scene 1002-21324-7 is of the Yukon River (1), 160 km northeast of Bethel, Alaska (Fig. 8). Stream features such as old meander scars (2), oxbow lakes (3), dendritic drainage patterns (4), mid-channel bars (5), point bars (6), sloughs (7) and chutes (8) are easily observed. Numerous thaw lakes are visible, indicating continuous permafrost areas. Also apparent are two smaller meandering rivers, the Kuskokwim (9) and Innoko (10). The Innoko River is a tributary of the Yukon River, whereas the Kuskokwim lies south of the Yukon and empties into Kuskokwim Bay south of Bethel, Alaska.

The Alaska Range (1) and the Wrangell Mountains (2), 170 km northeast of Valdez, are shown in image 110-20335-7

Fig. 9 Alaska Range and the Wrangell Mountains in southeastern Alaska.

(Fig. 9). Volcanic features including Mt. Wrangell (3) with caldera and side vent, Mt. Drum (4) and Mt. Sanford (5), volcanic cones, are apparent. Many of these volcanic features have been modified by glacial activity. Radial drainage patterns are evident on Mt. Sanford and Mt. Drum. Snow-covered glaciers (6), a possible small volcanic cone (7), and a fault (8) extending 100 miles across the northern portion of the photo are easily discernible.

A striking example of inverted topography, with anticlinal valleys and synclinal hills,[11] is shown on MSS image 1010-22142-7 (Fig. 10). The bedding planes in most of these structures between Cape Beaufort (1) on the Chukchi Sea (3) and the DeLong Mountains (2) are apparent. The Kukpowruk (4)

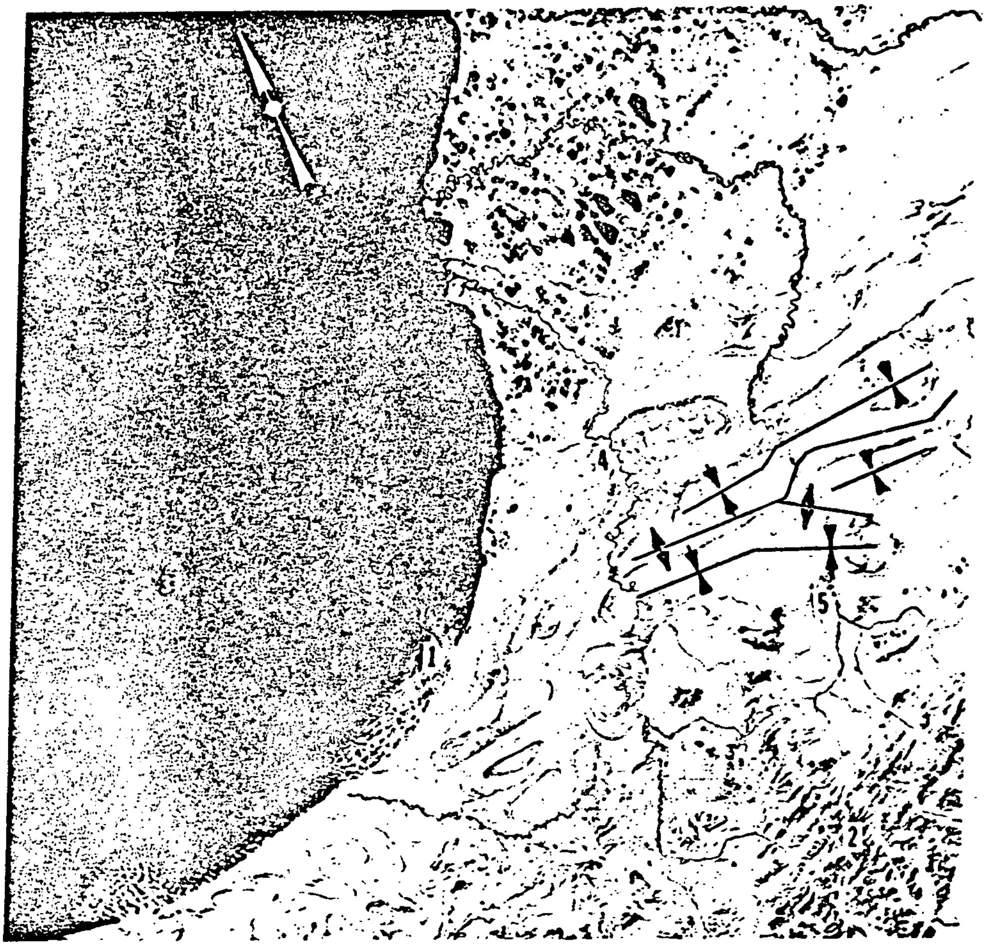


Fig. 10 Structural features near Cape Beaufort, Alaska.

and the Kokolik (5) Rivers eroding across the geological structures are probably superimposed streams.[12] The numerous thaw lakes are an indication of continuous permafrost.

The Chitina River (1) 370 km east of Anchorage, Alaska, is clearly visible in MSS image 1062-20221-7 (Fig. 11). The Wrangell Mountains (2) are to the north and the Chugach Mountains (3) to the south. In the Chugach Mountains, Bagley Icefield (4) and Bremner (5) and Tana (6) Glaciers with well-developed medial (7), terminal (8), and recessional moraines are easily defined. Also apparent are two abandoned glacial valleys (9) and Gates (10) and Bernard (11) Glaciers with well defined medial and lateral moraines.

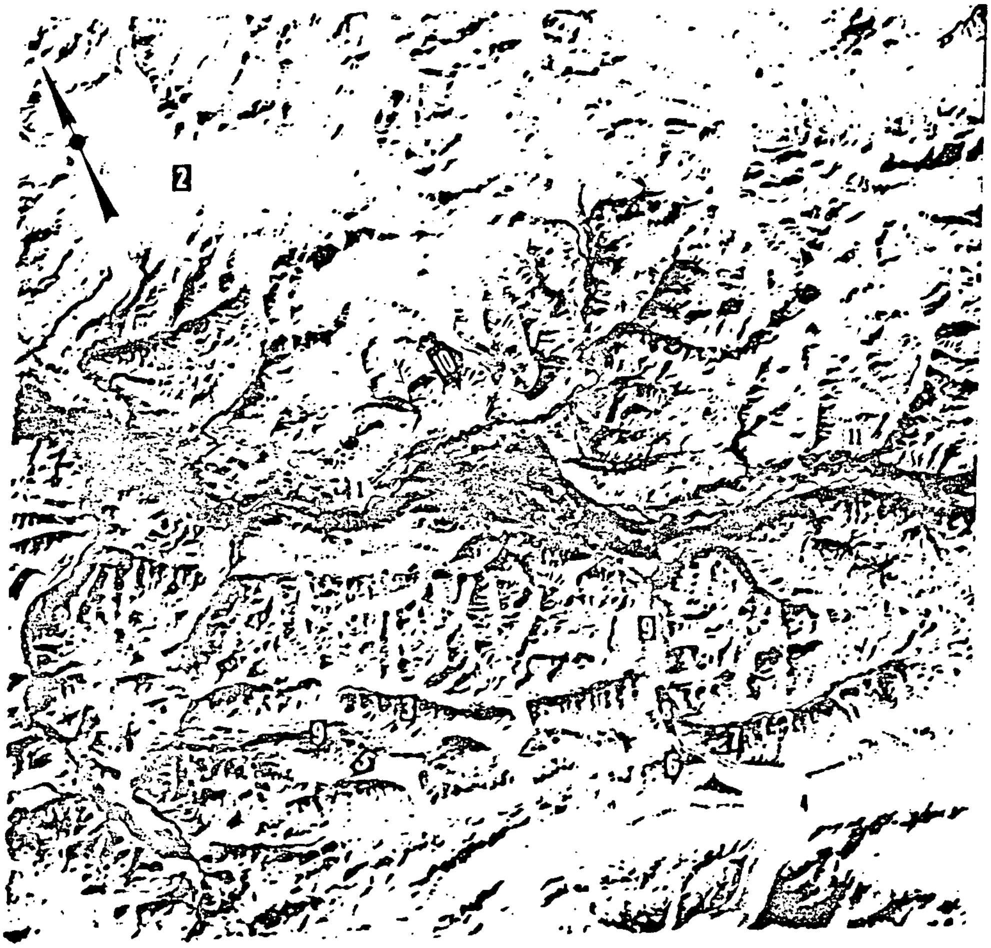


Fig. 11 Glacial features in the Wrangell Mountains, Alaska.

Coastal Sedimentation and Related Processes in Cook Inlet, Alaska

Suspended sediment is currently one of the most serious and detrimental pollutants in all water bodies. It is estimated that newly developing areas including agricultural lands brought into production may produce as much as 20,000-30,000 times more sediment than natural, undisturbed areas.[13] The high suspended sediment concentration is particularly troublesome in navigable waterways and harbors where siltation causes enormous economic impact. Cook Inlet is a cold water estuary in which sedimentation is of continuing concern. Synoptic views sequentially obtained from the ERTS-1 have proved to be useful in recognizing regional hydrologic and oceanographic relationships in this area. Recognition of these relationships is possible because the high suspended sediment concentration in the inflowing fresh water contrasts with the inlet water functioning as a natural coloring agent by which the surface circulation of tidal and long-shore currents is made visible in MSS bands 4 and 5. The sequential synoptic views of the Cook Inlet area allow the relationships to be monitored over extended periods of time.

During the first 6 months of the ERTS program the spacecraft completed eight cycles over the inlet. A few of the earliest images, taken during cycles 1 and 2 in August and cycles 3 and 4 in September, clearly show coastal landforms, suspended sediment distribution and circulation patterns. The high sedimentation rate and current velocities in Cook Inlet cause changes in the distribution and configuration of the tidal flats. These changes can be observed on the ERTS MSS imagery bands 5 and 7.

On MSS frame 1015-21022-5, taken 7 August (Fig. 12), the currents along the west shore of the inlet between MacArthur River (1) and Tuxedni Bay (2) are clearly visible. The glacial streams flowing from the Chigmit Mountains along the shore have a distinct tone related to their high suspended sediment load. Current direction in the inlet can be inferred from the shape and location of the sediment plumes. At the time of satellite overflight, currents were moving in a northerly direction as seen by the sediment plumes from the Drift (3) and Big (4) Rivers. Relative differences in sediment concentration of the inlet water are evident. Tidal flats (5) are observable as a gray border on the coastline. Lighter gray tones occur away from shore and indicate either deposition, mixing, or rapid sediment transport. Relict sediment patterns visible far off shore indicate the direction of tidal currents and net water movement through several tide cycles. Mt. Spurr (6), one of many volcanoes in the northern Aleutian Range, is visible. Lake Chakachamna (7), a glacial lake, and numerous glaciers (8) are also apparent in this scene.

MSS scene 1049-20512-5 (Fig. 13), taken 10 September 1972, shows the snowcapped Kenai Mountains (1) east of the Kenai lowlands (2), a flat, swampy glacial plain. The East (3) and West (4) Forelands geographically divide the inlet. Sediment plumes at the mouths of the Big (5) and Drift (6) Rivers indicate the direction of the near-shore current in Redoubt Bay (7). A counterclockwise current (8) is faintly visible around the northern and western portions of Kalgin Island (9). This pattern was verified by direct aerial observation from 6000 ft at the time the satellite passed. The tide front in Cook Inlet progresses from the inlet mouth to Anchorage (nearly 150

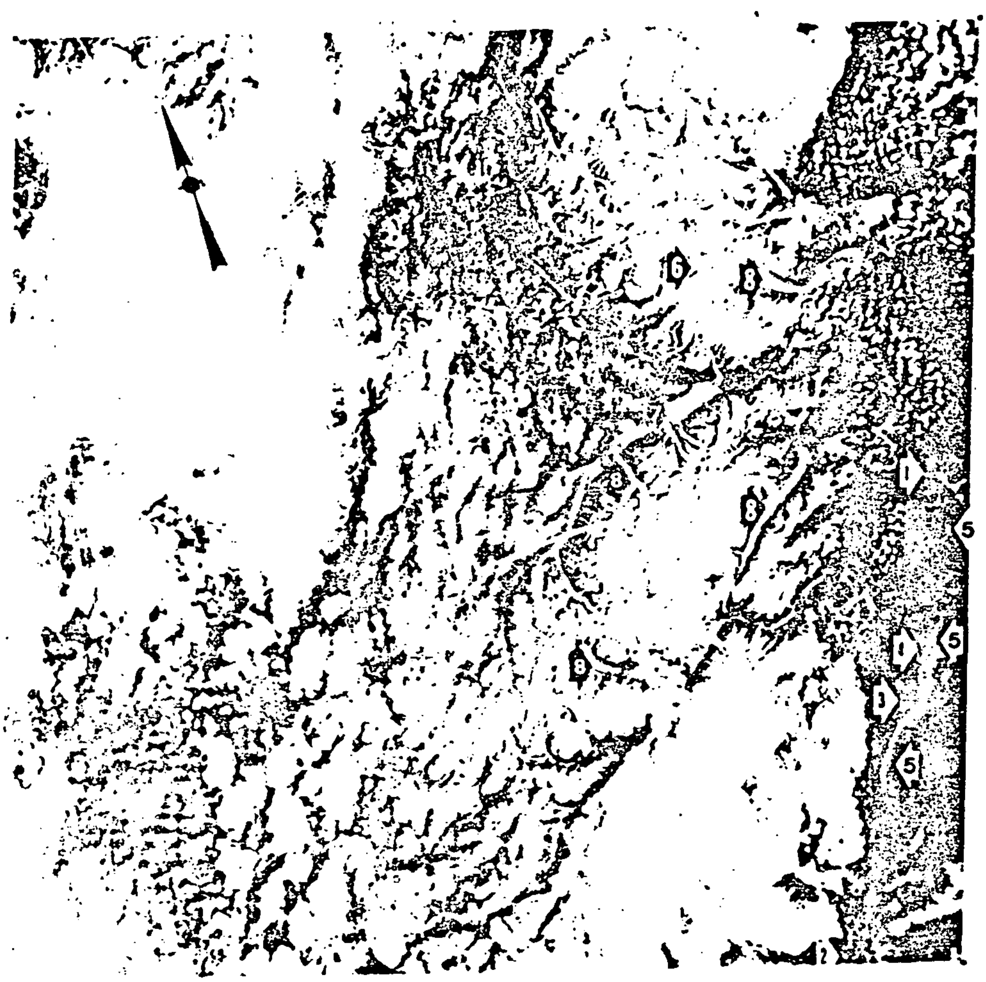


Fig. 12 The west shore of Cook Inlet between MacArthur River and Tuxedni Bay.

miles) in approximately 4½ hours. It moves faster along the east shore, being diverted in that direction by the Coriolis force. It moves past the East Foreland, a large peninsula protruding some 10 miles into the inlet, and is partially diverted across the inlet, where it abuts the West Foreland. At this point, part of the diverted front moves south of the West Foreland and the remainder moves north. This circulation pattern is repeated twice daily, and these two daily flood tides produce the counterclockwise pattern.[3] Extensive tidal flats (10) are visible along the west shore from the West Foreland past Harriet Point (11) to Tuxedni Bay. A large amount of suspended sediment is being deposited by the Tuxedni River (12) and is transported between Chisik Island (13) and the mainland. Sediment plumes indicating a southern flow are visible at the mouths of the Kasilof (14) and Kenai (15) Rivers. The gray

Fig. 13 Central portion of Cook Inlet, Alaska.

tone of Lake Tustumena (16) is attributed to high suspended sediment concentration.

The richness of the ERTS satellite imagery in information on ocean circulation and coastal processes thus is evident. Due to frequent cloudy days it will take considerable time before enough repetitive coverage is acquired to fully work out all the relationships. However, ERTS-1 already has yielded sufficient observational data on transport-circulation processes to significantly improve our understanding of the regional relationships between river hydrology, sediment distribution and near-shore oceanography in Cook Inlet.

Conclusions

The ERTS-1 system performance exceeds expectations. The feasibility of rapidly producing accurate thematic maps using ERTS-1 imagery has been demonstrated for arctic and subarctic regions. Using stereographic mapping techniques, it became immediately apparent that more geologic detail could be seen on the ERTS-1 imagery than could be mapped at a scale of 1:1,000,000. All major geomorphic features such as mountain ranges, drainage patterns, glaciated valleys, moraines, modified morainal topography, thaw lakes, floodplains, alluvial fans and terraces, and eolian deposits were recognizable.

A surficial geology map at a scale of 1:1,000,000 has been prepared utilizing MSS imagery. Seven surficial geology units, eight vegetative units and four permafrost terrain units were delineated in 153,400 km^2 of the Kobuk-Koyukuk-Yukon area of north central Alaska. The detail available from ERTS-1 imagery at 1:1.0 million scale compared favorably to the detail available on U.S. Geological Survey Miscellaneous Geologic Investigation Maps 290, 437, 459 and 554 at a scale of 1:250,000. It was established that the surficial geology results correlated closely with these published surficial geology maps. Equally good vegetation distribution and permafrost maps have been prepared.

Although sufficient cloud-free coverage of the Cook Inlet area is not yet available, it is clear from the usable imagery we have received that boundaries between major water types, river plumes, tidal currents and major circulation patterns can be seen. Assuming continued operation of the ERTS-1 multispectral scanner, there is no doubt that it will be possible to deduce major sediment distribution and deposition patterns in the inlet and near the harbors and docking facilities at Anchorage, Homer, Seldovia, Kenai, Ninilchik and Nikiski, Alaska.

References

[1]National Aeronautics and Space Administration, "Ecological surveys from space," NASA SP-230, Scientific and Technical Information Division, Washington, D.C., 1970, 75 p.

[2]Wagner, D.G., Murphy, R.S., and Behlke, C.E., "A program for Cook Inlet, Alaska for the collection, storage and analysis of baseline environmental data," Institute of Water Resources, Report No. IWR-7, University of Alaska, College, Alaska, 1969, 284 p.

[3]Evans, C.D., Buch, E., Buffler, R., Fisk, G., Forbes, R., and Parker, W., "The Cook Inlet environment, a background study of available knowledge," Resource and Science Service Center, University of Alaska, Anchorage, Alaska, 1972.

[4]McKim, H.L., Marlar, T.L., and Anderson, D.M., "The use of ERTS-1 imagery in the national program for the inspection of dams," USA CRREL Special Report 183, Hanover, New Hampshire, 1972, 19 p.

[5]Haugen, R.K., McKim, H.L., Gatto, L.W., and Anderson, D.M., "Cold regions environmental analysis based on ERTS-1 imagery," Proceedings of the 8th International Symposium on Remote Sensing of Environment, 2-6 October 1972, University of Michigan, Ann Arbor, Michigan, 1972, 12 p.

[6]Trytikov, A.D., "Perennially frozen ground and vegetation," in Principles of Geocryology, Part II, Engineering Geocryology, Chapter XII, Academy of Sciences of the U.S.S.R., V.A. Obruchev Institute of Permafrost Studies, Moscow, 1959, p. 399-421.

[7]Hopkins, D.M., Karlstrom, T.N.V., and others, "Permafrost and ground water in Alaska," U.S. Geol. Survey Prof. Paper 264-F, 1955, p. 113-146.

[8]Brown, R.J.E., "Factor influencing discontinuous permafrost in Canada," in The Periglacial Environment, Past and Present; T.L. Péwé (Ed.), McGill-Queens University Press, Montreal, 1969, p. 11-53.

[9]Péwé, T.L., "Permafrost and its effects on life in the North," Oregon State University Press, Corvallis, Oregon, 1966, 40 p.

[10]Ferrians, O.J., "Permafrost map of Alaska," U.S. Geol. Survey Misc. Geol. Inv. Map I-445, scale 1:2,500,000, 1969.

[11]United States Geological Survey, "Geology of the Arctic Slope of Alaska," USGS Oil and Gas Investigations Map, OM-126.

[12]Atwood and Atwood, "Working hypothesis of the physiographic history of the rocky mountain regions," Bull. Geol. Soc. Amer., vol. 49, 1938.

[13]Environmental currents, Environmental Science and Technology, vol. 6, no. 12, 1972, p. 965.

PREPRINT
Proceedings of the ERTS-1 Symposium
Goddard Space Flight Center
5-9 March 1973

Sediment Distribution and Coastal Processes in Cook Inlet, Alaska

D.M. Anderson, L.W. Gatto
H.L. McKim, A. Petrone

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

Sediment Distribution and Coastal Processes in Cook Inlet, Alaska

Duwayne M. Anderson, Lawrence W. Gatto, Harlan L. McKim
and
Anthony Petrone

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

Abstract

Regional hydrologic and oceanographic relationships in Cook Inlet, Alaska have been recognized from sequential ERTS-1 MSS imagery. Coastline configuration is well defined on bands 6 and 7 of images 1103-20513, 1103-20520, 1103-20522, 1104-20572, 1104-20574 and 1104-20581. Current patterns are visible in the inlet because of differential concentrations of suspended sediment. These patterns are most evident on bands 4 and 5. The circulation patterns within Cook Inlet are controlled primarily by the interaction between the semi-diurnal tides and the counter clockwise Alaska current. In general, heavily sediment laden water is seen to be confined to portions of the inlet north of the Forelands and west of Kalgin Island. Tongues of clear oceanic water are observed to enter the inlet through Kennedy Channel along the east shoreline in the vicinity of Cape Elizabeth. A recurring counterclockwise circulation pattern observed around Kalgin Island seems to result from the interplay of the northerly moving water along the east shore and the southerly moving, sediment laden, water along the west side of the inlet. Prominent, fresh water plumes, heavily laden with sediment are visible at the mouths of all major rivers. Relect plumes from as many as three tidal stages have been recognized. Tidal flats and a number of unmapped cultural features appear prominently in bands 5 and 6 of a number of the images.

INTRODUCTION

The Cook Inlet area of south central Alaska (Fig. 1) is a transportation, industry and population center. With pressure mounting rapidly here for extensive development, it is necessary to continue the environmental research required to increase our basic understanding of this region as soon and as vigorously as possible. Environmental disturbances caused by rapid development have potentially deleterious effects on land and water quality. One of the concerns of the Corps of Engineers is to help control and alleviate these adverse effects.

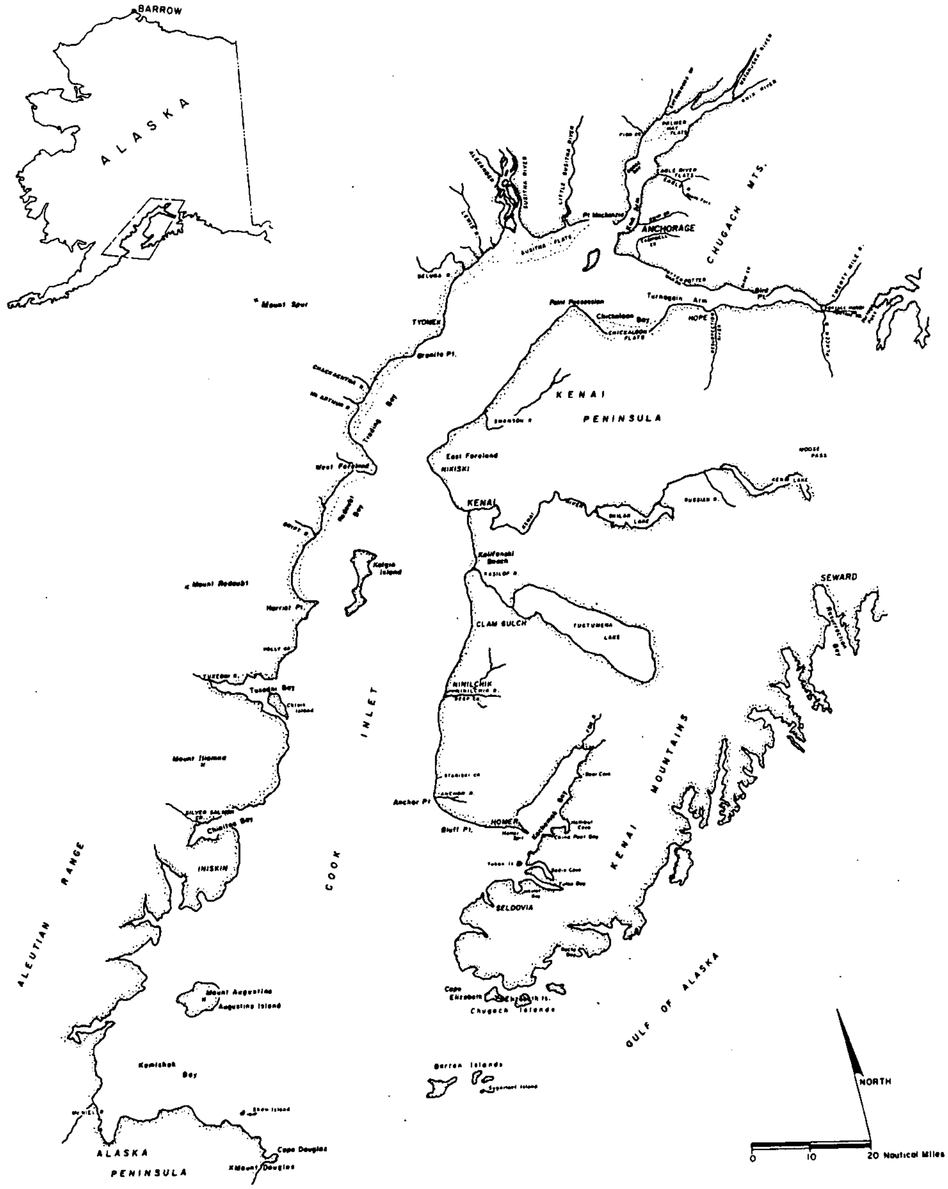


Figure 1. Regional Map of Cook Inlet

35

Suspended sediment currently is the most serious and detrimental pollutant in all water bodies. It is estimated that newly developing areas may produce as much as 20,000 - 30,000 times more sediment than natural undisturbed areas (Environmental Currents, 1972). High sediment loads are particularly troublesome in navigable rivers, inlets, channels and harbors where siltation is of enormous economic impact. To avoid or to aid in controlling such siltation problems, the Corps of Engineers wants to develop an improved understanding of the hydrology, sedimentation and coastal processes in cold water estuaries and inlets. Cook Inlet is a cold water estuary in which sedimentation and sediment redistribution is of continuing importance and concern. Synoptic views sequentially obtained from the ERTS-1 satellite provide data on transport-circulation processes which influence the sedimentation in Cook Inlet. The purpose of this investigation is to verify the utility and effectiveness of these data in the synoptic survey of coastal sedimentation and related processes in Cook Inlet.

BACKGROUND

In the Cook Inlet area the Corps of Engineers is particularly concerned with providing deep draft and small boat harbor improvements, maintaining deep draft berthing and maneuvering channels, controlling beach erosion and continuing harbor construction. To aid in performing these functions, data have been collected at the specific site locations. Efforts directed to the collection of regional data have been minor. This approach was also followed by other investigators. Rosenberg and others (1967 and 1969) examined the oceanographic processes in the Nikiski area. Various petroleum companies active in the area investigated the oceanographic processes around the mouth of the Drift River and in Trading Bay (Marine Advisors, 1966 and 1969). However, few efforts have considered the inlet as an entity. Sharma and Burrell (1970) investigated the distribution of bottom sediments in a large portion of the inlet. Wagner and others (1969) and Evans and others (1972) compiled all available information dealing with the environmental and oceanographic aspects of the region. Although the general oceanographic relationships are beginning to emerge, it is apparent that much remains to be learned.

GEOGRAPHIC SETTING

Cook Inlet is a large tidal estuary in south central Alaska. It is oriented in a northeast-southwest direction and is approximately 180 nautical miles long and increases in width from 20 nautical miles in the north to 45 nautical miles in the south. The inlet is bordered by extensive tidal marshes, lowlands with many lakes, and mountains (Fig. 3). Tidal marshes are prevalent around the mouth of the Susitna River, in Chickaloon Bay, Trading Bay and Redoubt Bay. The Kenai Lowland separates the inlet from the Kenai Mountains on the upper southeast side. The Susitna Lowland lies between the Talkeetna Mountains on the northeast and the southern Alaska Range on the northwest. The Kenai Mountains are adjacent to the inlet mouth on the southeast; the Alaska-Aleutian Range forms the western border.

ESTUARY CHARACTERISTICS

Coastline Characteristics

The coastal configuration of the inlet is characterized by sea cliffs extending from the head of Kachemak Bay to Turnagain Arm. Pocket beaches that occur along this coast are generally composed of sand and/or coarser sediment while finer grained material is present in lower energy locations. Along the northwest and west coasts from Point Mackenzie to Harriet Point an extensive coastal plain borders a shoreline of scattered sea cliffs and pocket beaches. From Harriet Point to Cape Douglas the steep mountains slope directly into the inlet in most locations and bayhead beaches form in many of the numerous small embayments along this coast. Sea cliffs are generally found only on the promontories along this coast.

Bathymetry

The depth of the upper inlet north of the forelands is generally less than 20 fathoms. The deepest portion, 45 fathoms, is located in Trading Bay just off the mouth of the MacArthur River (Sharma and Burrell, 1970). Turnagain and Knik Arms are the shallowest areas, with much of the bottom exposed as tidal flat at low tide. South of the forelands two channels, one between Kalgin Island and Harriet Point and another between Kalgin Island and the southeast shore, extend southward in the inlet and join in an area west of Cape Ninilchik. The deepest portion of the western channel, located between Kalgin Island and Harriet Point, is approximately 70 fathoms. The eastern channel is deepest just south of a line between the forelands. It is 75 fathoms in this area and rapidly shoals to approximately 30 fathoms until it merges with the western branch to form a single channel. South of Cape Ninilchik this channel gradually deepens to approximately 80 fathoms and widens to extend across the mouth of the inlet between Cape Douglas and Cape Elizabeth.

Tides/Tidal currents

The tides in Cook Inlet are semi-diurnal with two unequal high tides and two unequal low tides per tidal day (24 hours, 50 minutes) and high tide in Anchorage occurs 4.5 hours later than at the inlet mouth (Fig. 2). Mean diurnal tide range varies from 13.7 feet at the mouth

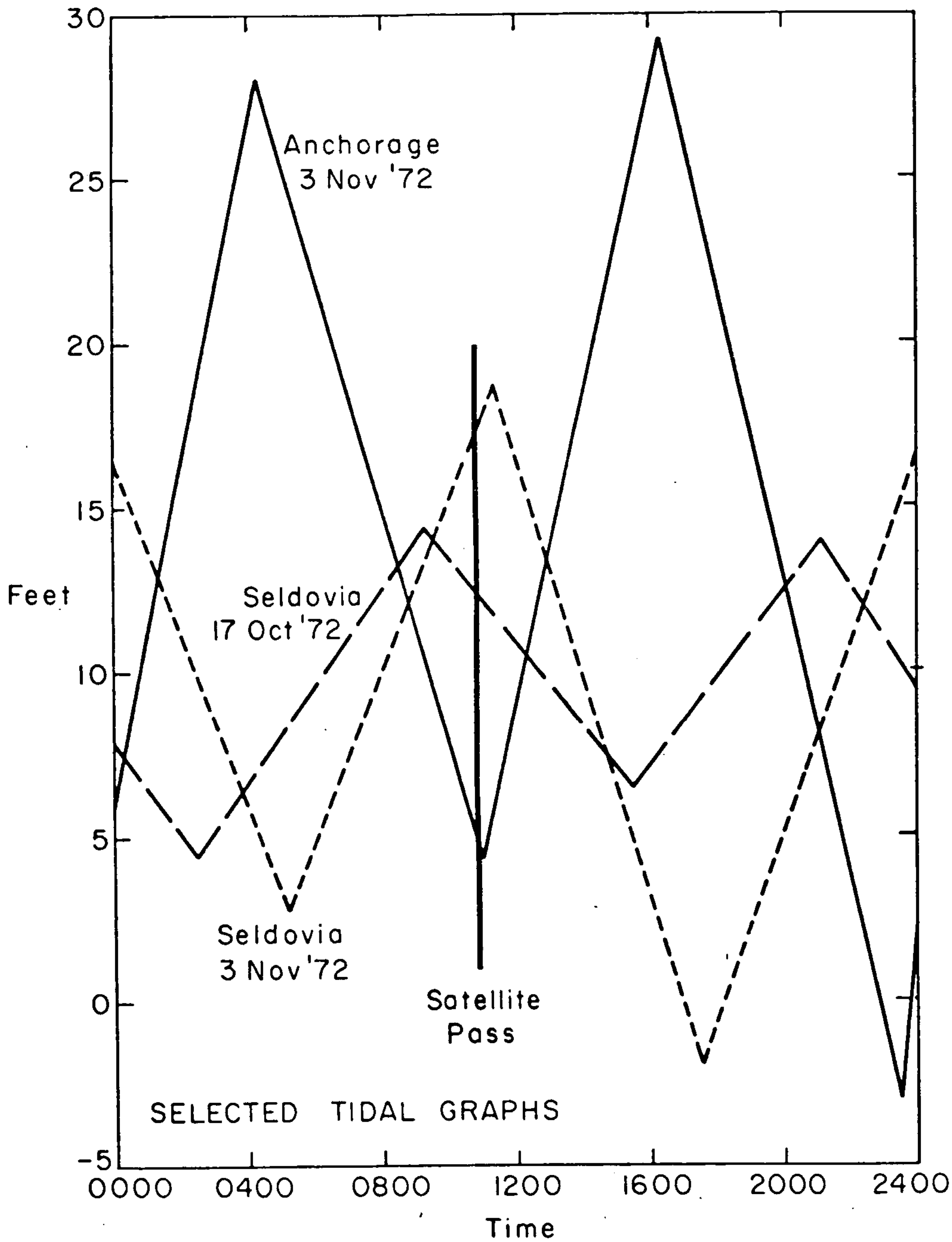


Figure 2. Selected Tidal Graphs

to 29.6 feet at Anchorage. It varies within the lower portion of the inlet from 19.1 feet on the east side to 16.6 feet on the west side (Wagner et al., 1969). The extreme tidal range produces tidal currents typically 4 knots and occasionally 6 to 8 knots (Horrer, 1967). The high Coriolis force at this latitude, the strong tidal currents and the inlet geometry produce considerable cross currents and turbulence throughout the entire water depth during both ebb and flood tides (Burrell et al., 1967). The turbulence is especially active along the eastern shore of the inlet.

Surface Circulation

The circulation of the inlet is influenced by bathymetry, morphometry and fresh water drainage (Evans et al., 1972). The water in the upper inlet is well mixed due to the large tidal fluctuations in this shallow, narrow basin. During summer when surface runoff is high there is a net outward movement of water from the upper inlet. With reduced runoff in the winter there is virtually no net outflow (Murphy et al., 1972). The middle inlet has a net inward circulation of cold, saline oceanic water up the eastern shore and a net outward flow of warmer and fresher inlet water along the western shore (Evans et al., 1972). These water types are well mixed vertically along the eastern shore but separated laterally resulting in a shear zone. In the lower inlet this lateral temperature and salinity separation is maintained but in the western portion vertical stratification occurs with colder, saline oceanic water underlying warmer, less saline inlet water. During tidal inflow the deeper oceanic water rises to the surface at the latitude of Tuxedni Bay and mixes with the inlet water (Kinney et al., 1970).

Sediment Distribution

The currents and circulation patterns are especially important in determining the distribution of suspended and bottom sediments throughout the inlet. The suspended sediment is mostly of glacial origin with the highest concentrations in the northern portion of the inlet, a well-mixed turbulent zone of strong tidal currents. Suspended sediment is nearly absent in the waters of the central and eastern portions at the inlet mouth. Bottom sediments have been grouped into three facies: a predominantly sand facies in the upper inlet, a sandy gravel with minor silt and clay facies in the middle inlet, and a gravelly sand and minor interspersed silt and clay facies in the lower inlet (Sharma and Burrell, 1970).

INTERPRETATION OF ERTS IMAGES

Coastal Configuration

The coastal landforms and cultural features along the Cook Inlet shoreline are most distinct on ERTS MSS bands 5, 6 and 7. The mountainous borders of the inlet on the southeast and the lower northwest and the coastal plain border on the upper northwest and east are easily recognized (Fig. 3). Homer spit and the Susitna River delta are apparent. The major cities and towns (Anchorage, Nikiski, Kenai, Homer and Seldovia) and some previously unmapped developments south of the mouth of the Drift River (6 on Figure 5) and on the southern shore of the West Forelands are readily identifiable.

Tidal Flat Distribution

The high sediment load in glacial rivers is the main source of material found in the tidal flats throughout the inlet. MSS band 5 and 7 images are ideal for analysis of these tidal flats. Because the major portion of sediment deposited in the inlet is carried by the Susitna and Knik Rivers (Rosenberg et al., 1967) the major portion of the tidal flats is located in the inlet north of the forelands (Fig. 3). In the lower inlet the tidal flats occur as bayhead bars in the numerous embayments along the western shore and northeast of Homer in Kachemak Bay. The high current velocities and frequent changes in current directions of the inlet water produce variations in the distribution and configuration of the flats. The migration of some major tidal flat channels and the redistribution of some tide flats in Knik and Turnagain Arms can be detected on MSS frame 1103-20513-5 (compare with the National Ocean Survey Navigational Chart 8553). A knowledge of these changes is particularly important in maintaining navigation channels and harbor facilities.

River Plumes

The sediment- laden rivers that discharge into the inlet produce sediment plumes which are visible on MSS bands 4 and 5. Figure 3 shows the distribution of plumes from some of the major rivers around the inlet. Although the Knik and Matanuska Rivers at the head of Knik Arm contribute a major portion of the sediment deposited in the inlet (Wagner et al., 1969) these rivers do not have distinct sediment plumes. The river-borne sediment is dispersed so quickly in this high energy area and the sediment concentration is so high (approximately 1350 mg/l;Kinney et al., 1970) in the inlet water at that location that a distinct plume is not formed. The Susitna River, another major sediment contributor, has only a small plume because the river discharge is reduced (Rosenberg et al., 1967) during the winter months (Fig. 3). In addition, the plume is less distinct because the inlet water at the mouth of the Susitna River has a high suspended sediment concentration (approximately 1540 mg/l; Kinney et al., 1970). MSS frame 1015-21022-5 (Fig. 4), taken 7 August, shows the sediment plumes from the Drift (3) and Big (4) Rivers during flood tide. The shape and location of the plumes can be used to infer the current direction along the west shore between MacArthur River (1) and Tuxedni Bay (2). Currents appear to be moving in a northerly direction. Relict sediment plumes in this area are visible far offshore and indicate the

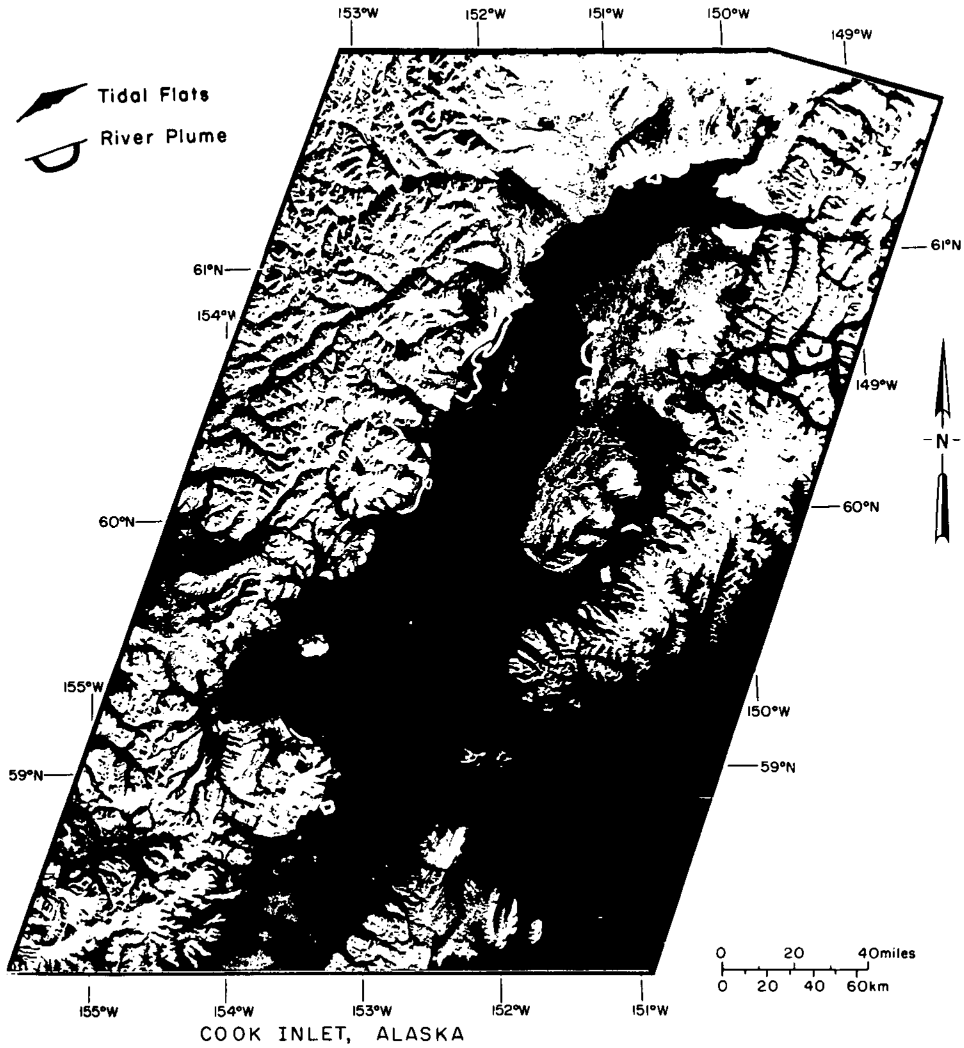


Figure 3. Tidal flat distribution and river plumes

41

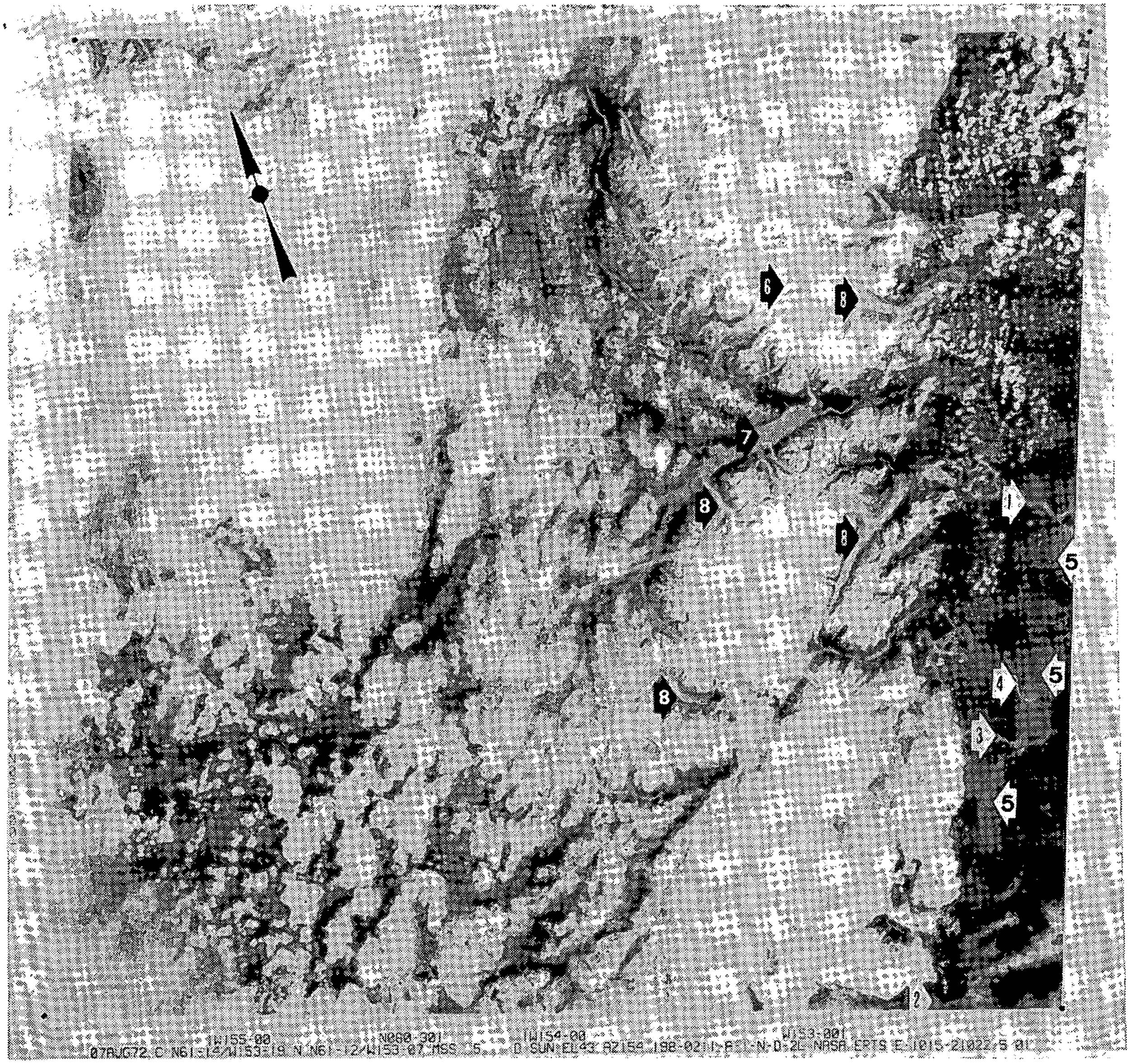


Figure 4. The west shore of Cook Inlet between MacArthur River and Tuxedni Bay

net water movement through several tide cycles. Tidal flats (5) are discernible as a gray border along the coastline. Mt. Spurr (6), one of the many volcanoes in the Chigmit Mountains, Lake Chakachamna (7) and numerous glaciers (8) are also apparent in this scene.

Tidal changes in the sediment plumes of the Big (5) and Drift (6) Rivers are shown in MSS scene 1049-20512-5 (Fig. 5) taken 10 September 1972. The southerly direction of the near-shore current during ebb flow in Redoubt Bay (7) is inferred by the shape of these river plumes. The sediment-laden water from Tuxedni River (12) is transported along the coast in a southerly direction between Chisik Island (13) and the mainland. This movement also indicates that the coastal currents were moving south along the west shore when the image was taken. The shape of the sediment plumes of the Kenai (15) and the Kasilof (14) Rivers indicate a southern current along the east shore in this locatinn. Other features on this scene are: snowcapped Kenai Mountains (1), Kenai Lowland (2), the East (3) and the West (4) Forelands, a counterclockwise current pattern (8) around Kalgin Island (9), tidal flats (10), Harriet Point (11), and Lake Tustumena (15) with a high sediment concentration.

Water Types

Bands 4 and 5 of MSS scenes 1103-20513, 1103-20520, 1104-20572 and 1104-20574 clearly show the distinction between the more sediment-free, saline oceanic water in the southeastern portion of the inlet and the sediment-laden, fresher inlet water in the northern and southwestern parts of the inlet. Recognition of this relationship is possible because the sediment in the inflowing fresh water functions as a tracer, making sediment distribution patterns visible. Daily changes and changes that occur every 18 days in this regional sediment distribution can be detected. Figure 6a shows differences in the main boundary between the oceanic and fresh water in the southern inlet on two successive days. The boundaries separate the water types during low tide in Anchorage and high tide in Seldovia (Fig. 2). The irregularity of the western portion of these lines may be due to the upwelling of cold, saline oceanic water that occurs in the western portion of the inlet (Evans et al., 1972; Kinney et al., 1970). The northern portion of the 4 November boundary is also quite irregular, possibly due to this upwelling effect. According to Bowden (1967) some estuaries are characterized by a salt wedge that moves headward into the estuary along the bottom while the fresh water outflow moves over this wedge and out the estuary. In Cook Inlet this subsurface tongue of oceanic water progresses headward and moves up the shoaling bottom of the inlet to the latitude of Tuxedni Bay where it rises to the surface south of Kalgin Island during flood tide (Kinney et al., 1970). The upwelling waters appear as a large area of clear water surrounded by sediment-laden water. This process produces a zone

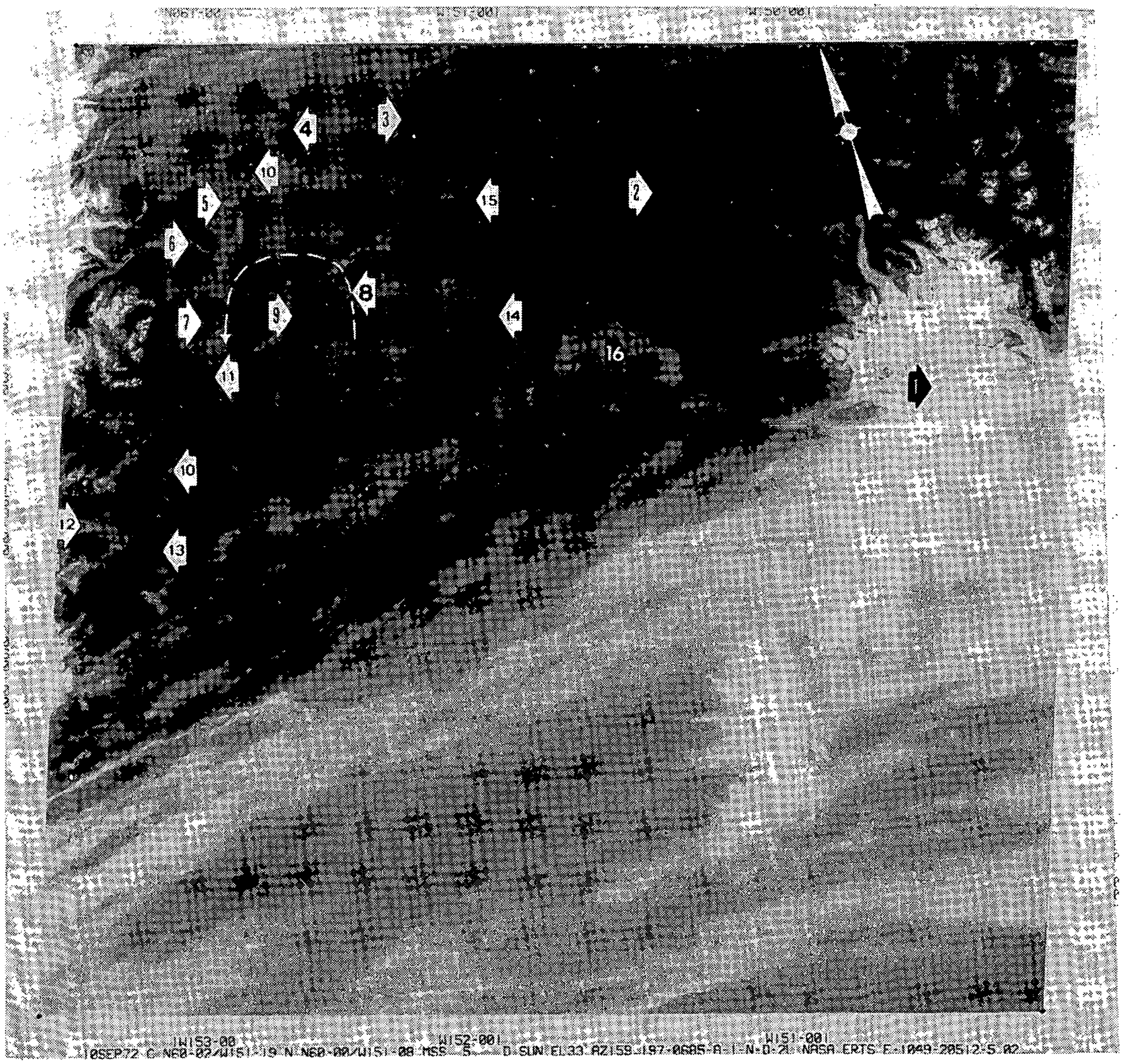
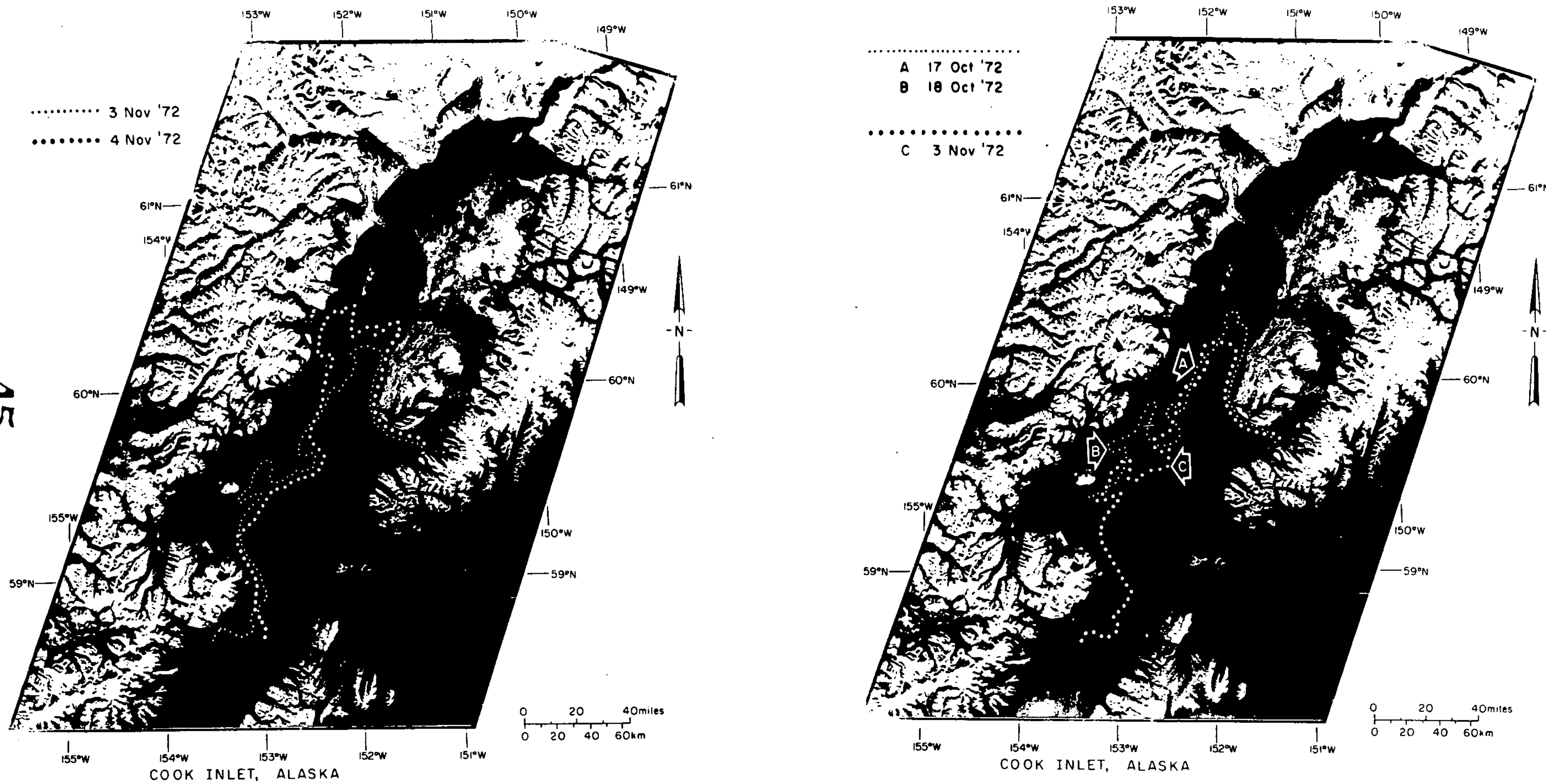


Figure 5. Central portion of Cook Inlet

44



A

B

Figure 6. Boundaries separating oceanic and inlet water

of high nutrient concentration in the photic zone at this location. This may be significant to the fishing industry since certain species of fish may tend to concentrate in this high nutrient area. Changes in the boundary over an 18-day cycle are shown in Figure 6b. These boundaries are generally comparable to those in Figure 6a. Although changes in the sediment distribution and surface circulation produce some obvious alterations in the regional distribution of water types, the overall relationship of the water appears to remain consistent with time.

Surface Circulation

The high suspended sediment concentration in the inflowing fresh water and in the inlet water functions as a natural coloring agent by which the surface circulation of tidal and long-shore currents can be observed. The currents are most visible in MSS bands 4 and 5. Figure 7 shows the surface circulation in the inlet based on published data (Evans et al., 1972) and inferred from ERTS-1 imagery. The regional circulation of the inlet water as previously understood was observed and verified with few changes in the ERTS images. The clear oceanic water enters the inlet at flood tide along the east side around the Barren Islands. A portion of this clear water is forced into the inlet by the counterclockwise Alaska Current in the Gulf of Alaska. A distinct tongue of this oceanic water, which can be seen on MSS frames 1104-20574-5 and 1103-20520-4, occupies the southeastern portion of the inlet and becomes less distinct in a northeast direction by mixing with the sediment in the upper inlet water around Ninilchik. The tide front progresses up the inlet (nearly 150 miles) in approximately 4 1/2 hours. It moves faster along the east shore, being diverted in that direction by the Coriolis force. A back eddy not previously reported (dotted arrow) was apparent on MSS frames 1103-20513-5, 1103-20520-5 and 1104-20574-5 just offshore from Clam Gulch. The eddy forms in the slack water area northeast of Cape Ninilchik during flood tide. The tide front continues past the East Foreland, a large peninsula protruding some 10 miles into the inlet and is partially diverted across the inlet, where it abuts the West Foreland. At this point, part of the diverted front moves south of the West Foreland and the remainder moves north. This circulation pattern is repeated twice daily during the two daily flood tides. The result is a counterclockwise circulation pattern around Kalgin Island (Fig. 5). The circulation of surface water north of the forelands appears to be similar to that previously reported (Evans et al., 1972). The ebb flow in the inlet moves predominantly along the northeastern shore past the forelands. This pattern was discernible on the imagery except for a previously reported counterclockwise pattern (dashed arrow) formed north of the forelands. This pattern is formed as the ebbing waters abut the West Foreland and some are diverted across the inlet and move headward with the flood current along the east shore.

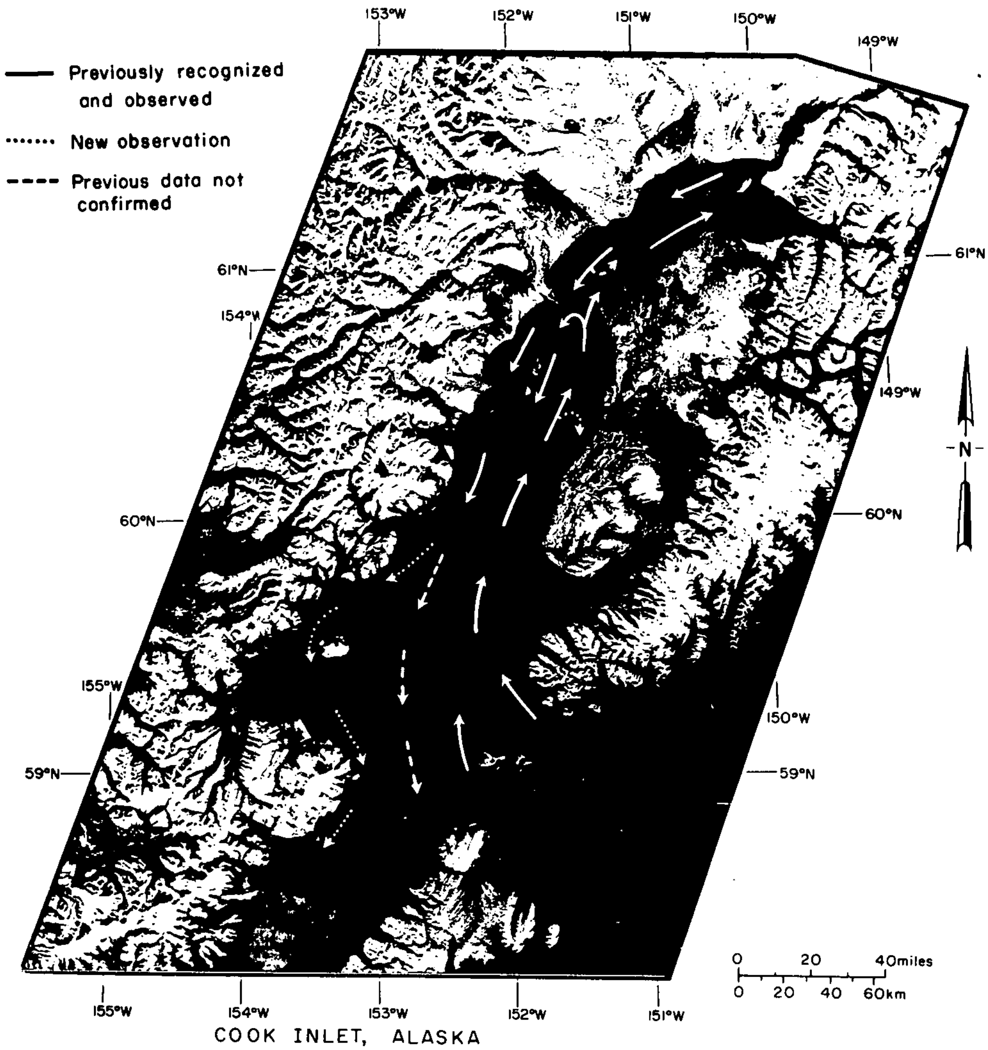


Figure 7. Surface current patterns

47

As the sediment-laden ebbing water moves past the area of Chinitna Bay (Fig. 1) it appears to flow along the shoreline and circulate around the west side of Angustine Island in Kamishak Bay. It continues to parallel the coast past Cape Douglas and progresses through Shelikof Strait. This circulation pattern in Kam ishak Bay was not previously reported but is clearly visible on the MSS imagery.

CONCLUSIONS

The richness of the ERTS satellite imagery in information on ocean circulation and coastal processes is clearly evident. The changes in the distribution and configuration of tidal flats can be monitored with MSS band 5 and 7 images. Knowledge of these changes is particularly important in maintaining navigation channels and harbor facilities. Upwelling, which produces a region of high nutrient concentration, can be detected on MSS bands 4 and5. This is significant to the fishing industry of Homer, Ninilchik and Kenai, since certain species of fish may tend to concentrate in this region. The distribution of sediment and the surface circulation are also visible on MSS bands 4 and 5. ERTS-1 will permit the collection of sufficient observational data on transport-circulation processes to develop an understanding of the regional relationships between river hydrology, sediment distribution and near-shore oceanography in Cook Inlet.

48

REFERENCES

Bowden, K. F., 1967, Circulation and diffusion: Estuaries, Amer. Assoc. for the Advancement of Science Publ. No.83, Washington, D. C. p. 15-36.

Burrell, D. C. and D. W. Hood, 1967, Clay - Inorganic and organic-inorganic association in aquatic environments, Part II: Institute of Marine Science, University of Alaska, College, Alaska.

Environmental currrents, 1972, Environmental Science and Technology, vol. 6, no. 12, p. 965.

Evans, C. D., E. Buch, R. Buffler, G. Fisk, R. Forbes and W. Parker, 1972, The Cook Inlet environment, a background study of available knowledge: Resource and Science Service Center, University of Alaska, Anchorage, Alaska.

Horrer, P. L., 1967, Methods and devices for measuring currents: Estuaries, Amer. Assoc. for the Advancement of Science Publ. No. 83, Washington, D. C. p. 80-89.

Kinney, P. J., J. Groves and D.K. Button, 1970, Cook Inlet Environmental data. R/V Acona Cruise 065- May 21-28, 1968: Institute of Marine Science Report R-70-2; University of Alaska, College, Alaska, 120p.

Marine Advisors, Inc., 1966a, Currents near the mouth of Drift River, Cook Inlet, Alaska: San Diego, California.

Marine Advisors, Inc., 1966b, Hydrographic survey in Trading Bay, Cook Inlet, Alaska: San Diego, California.

Murphy, R. S. and R. F. Carlson, 1972, Effect of waste discharges into a silt laden estuary, a case study of Cook Inlet, Alaska: Institute of Water Resources Report IWR 26, University of Alaska, College, Alaska, 42p.

Rosenberg, D.H., D. C. Burrell, K. V. Natarajan and D. W. Hood, 1967, Oceanography of Cook Inlet with special reference to the effluent from the Collier Carbon and Chemical Plant: Institute of Marine Science Report No. IMS-67-3, University of Alaska, College, Alaska, 80p.

Rosenberg, D. H., K. V. Natarajan and D. W. Hood, 1969, Summary Report on Collier Carbon and Chemical Corporation Studies in Cook Inlet, Alaska, Parts I and II, November 1968-September 1969: Institute of Marine Science Report No, 69-13, University of Alaska, College, Alaska.

Sharma, G. D. and D. C. Burrell, 1970, Sedimentary Environment and Sediments of Cook Inlet, Alaska: Amer. Assoc. Pet. Geologists, vol. 54, no. 4, 9. 647-654.

Wagner, D. G., R. S. Murphy and C. E. Behlke, 1969, A program for Cook Inlet, Alaska for the collection, storage and analysis of baseline environmental data: Institute of Water Resources, Report No. IWR-7, University of Alaska, College, Alaska, 284p.